NEW LATE CAINOZOIC ROCK UNITS AND DEPOSITIONAL ENVIRONMENTS, LAKE FROME AREA, SOUTH AUSTRALIA

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Summary

CALLEN, R. A., & TEDFORD, R. H. (1976).—New late Cainozoic rock units and depositional environments, Lake Frome area, South Australia. *Trans. R. Soc. S. Aust.* **100**(3), 125-167, 31 August 1976.

Five new rock units are defined for the Lake Frome area of South Australia.

The Namba Formation of Miocene age constitutes fine grained immature muddy sediments laid down in a low-energy fluviatile and lacustrine environment, possibly partly estuarine or lagoonal. Climate was subtropical or warm temperate with high rainfall, but seasonal aridity. Aphanitic oolitic lacustrine dolomite and palygorskite are included in this sequence. The Flinders Ranges had very low relief. The overlying and intertonguing Willawortina Formation represents alluvial fan deposits with minor lacustrine phases, recording the beginning of the late Cainozoic uplift of the Flinders Ranges, during which the Miocene lake was greatly reduced in area.

The Millyera Formation, constituting laminated ostracode bearing clay, fine sand, and charophyte limestone, records lacustrine deposition during the Pleistocene. This took place in an enlarged ancestral Lake Frome. The essentially fluviatile and aeolian deposits of the Eurinilla Formation and Coonarbine Formation were deposited during the late Pleistocene and early Recent. Arid and pluvial climates alternate in the late Tertiary and Quaternary. Drainage trends and the predecessor of Lake Frome were established, closely approximating present day geography. During deposition of the Coonarbine Formation the seif dunes of the southern Strzelecki Desert formed.

Introduction

Mapping on the FROME (Callen 1975), and CURNAMONA 1:250 000 geological sheets has resulted in differentiation of several Tertiary and Quaternary rock units which can be traced throughout the Lake Frome area (the region south of Lake Callabonna between the Flinders, Barrier and Olary Ranges). The Eyre Formation has been defined previously (Wopfner *et al.* 1974). It lies immediately beneath the units described here for the Lake Frome area and can be recognised over a much wider region. The other units are at present restricted to the Lake Frome region, though correlation with units elsewhere, especially in the Lake Eyre Basin, is generally possible on a firm basis.

There was a low divide between the depositional areas of Lakes Frome and Eyre, suggested by the distribution of arenaceous material in the Miocene rocks. The development of this divide is clearly described by Wopfner (1974, p. 6). Thus the Lake Eyre and Lake Frome areas formed two distinct depositional basins during late Tertiary times; different sets of formal names are used for rock units in each. In late Tertiary and Quaternary times the Flinders Ranges achieved their present dimensions, completely separating the two basins by a range of mountains.

This paper describes five rock units requiring formalization under the Australian Code of Stratigraphic Nomenclature (1973), commenting on the paleo-environmental inferences to be drawn from them. The nomenclature supersedes that shown on the FROME geological map, relationships between units now being on firmer basis. The paper is divided into two parts, dealing with essentially Tertiary and Quaternary units respectively. New geographic names have been formalized with the Geographic Names Board of South Australia

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(pers. comm. 1973) and are designated with a superscript wherever they first appear, thus: Lake Namba[x]. Geologic names have been cleared with the Central Registry (Canberra, 1973). The paper derived from a report by Callen (1974)[1] and an M.Sc. thesis (Callen, 1976)[2]. Additional stratigraphic data may be found in this thesis.

Previous work includes the early geological surveys of Selwyn (1860), Brown (1884) and later of Jack (1930) and Kenny (1934). More recently Ker (1966), Krinsley *et al.* (1968) and Draper & Jensen (1975, in prep.) have reported on hydrology and geology. The margins of the basin have been the subject of regional mapping programmes by the South Australian and New South Wales geological surveys, on 1:250 000 scale. Relevant to this report are Leeson (1967)[3], Firman (1971)[4] and Coats (1973). A detailed basin study of the older unit NAMBA FORMATION is in progress and will be reported at a later date. A preliminary account of the stratigraphy is presented in Callen (1976), which gives the structural and tectonic setting.

The terms used to describe the sedimentary rocks are those of Folk *et al.* (1970), unless indicated otherwise. Colours are given symbolically in terms of Munsell Colour Code (Geological Society of America 1951). A relative scale was used for designating the thickness of cross-bedding, as follows: very small <1 cm, small 1–5 cm, medium 5–50 cm, large 0.5–2 m, very large >2 m. In the designation of contact features, core width places a limit on the interpretation, as it does on maximum grain size: cobbles and boulders are interpreted from the proportion and shape of fragments ground down and broken by the drilling operation, and nature of petrophysical log response.

The older units (Pt I) were described mainly from bores, the younger (Pt II) from outcrop. Knowledge of the younger units was derived from detailed investigation of over 100 trenched outcrop sections. Where possible units were traced between sections. Fossil soils were an aid to stratigraphic interpretation.

The location of the sections is shown in Fig. 1, Tables 1 and 3 summarizing rock unit properties, palaeontology and geomorphology. Symbols are in Fig. 2.

The subsurface sections were studied from cores derived from bores drilled by the South Australian Department of Mines and private companies. Some percussion and rotary cutting were used to assist correlations, but those utilized for type sections were cored continuously, and are available for inspection at the South Australian Department of Mines Core Laboratory. Petrophysical logs were run in all cases. The lithological descriptions were supplemented by binocular microscope examination, and clay (x-ray diffraction) and grain size (sieve and pipette) analyses were performed by Drs R. N. Brown and B. G. Stevenson respectively of the Australian Mineral Development Laboratories.

The text is regarded as a supplement to the diagrams and tables, descriptions in Tables 1 and 3 should be read first. Complete descriptions of each section are given in the appendices, wherein the sequences are described as they occur on the earth's surface—i.e. youngest at top, oldest at base. Depths to the top of each unit or bed from the bore collar are given, and the thickness is placed at the start of its description. In each unit, description of the dominant lithology is capitalized; followed by qualifying descriptors referring to each lithology in the same order.

Division into units in the reference sections is intended as an aid to identification of the appropriate intervals in the descriptions (Section 12, Fig. 3), not a formal subdivision. Core loss is indicated in the bore logs (Fig. 3 sections 10, 11 & 12).

Pt. I—Older Cainozoic Rock Units

A general definition of each unit giving salient features, age and geomorphic setting is presented in Table 1, representative sections in Fig. 3. Appendix 1 gives detailed descriptions of individual units.

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[1] Callen, R. A. (1974).—New Rock Units and Climate of the Cainozoic, Lake Frome area, South Australia. *S. Aust. Dept. Mines Rept.* 74/75 unpub.

[2] Callen, R. A. (1976).—Stratigraphy, sedimentology and uranium deposits of Tertiary rocks, Lake Frome area, South Australia. M.Sc. thesis, University of Adelaide (unpublished).

[3] Leeson, B. (1967).—Geology of *Balcanoona* 1:63 360 map area. *S. Aust. Dept. Mines Rept.* RB 64/92 unpub.

[4] Firman, J. B. (1971).—Regional stratigraphy of surficial deposits in the Great Artesian Basin and Frome Embayment in South Australia. *S. Aust. Dept. Mines Rept.* RB 71/16 unpub.

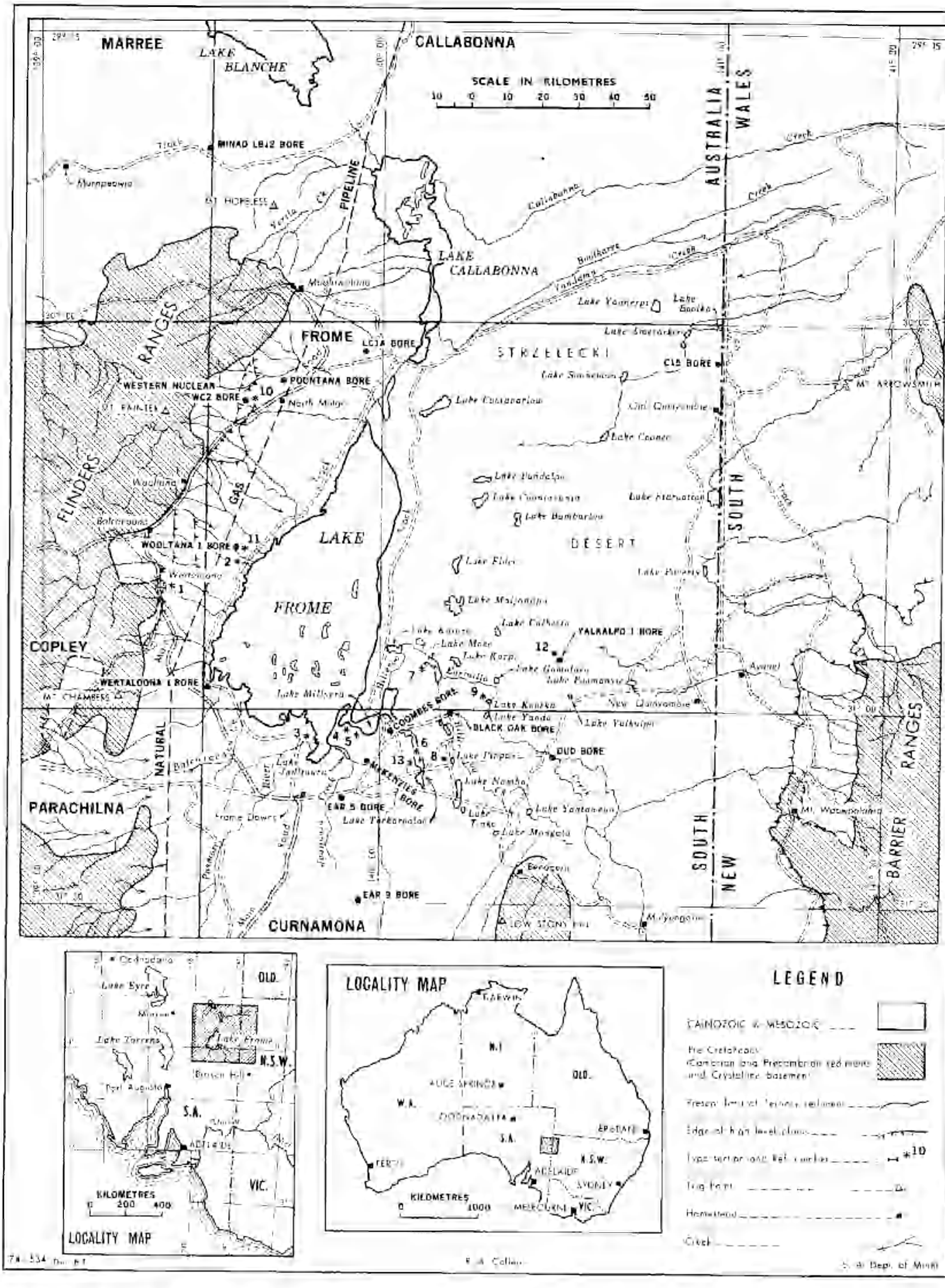


Fig. 1. Locality map, Lake Frome area—location of type sections. Numbered sections shown in Figs 3, 14, 15.

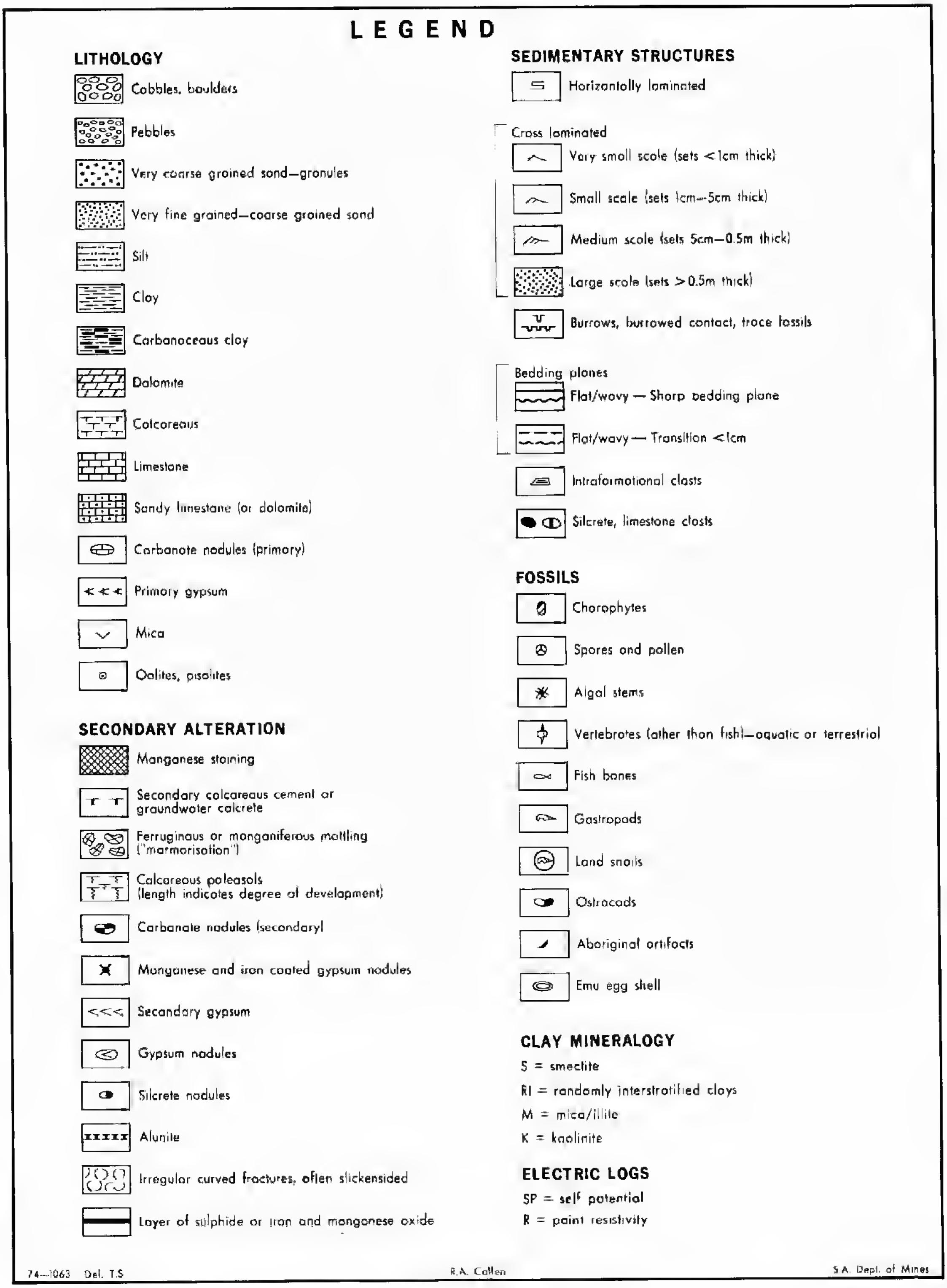

LEGEND
LITHOLOGY
Cobbles, boulders
Pebbles
Very coarse grained sand—granules
Very fine grained—coarse grained sand
Silt
Clay
Carbonaceous clay
Dolomite
Calcareous
Limestone
Sandy limestone (or dolomite)
Carbonate nodules (primary)
Primary gypsum
Mica
Oolites, pisolites
SECONDARY ALTERATION
Manganese staining
Secondary calcareous cement or groundwater calcrete
Ferruginous or manganiferous mottling ("marmorisation")
Calcareous paleosols (length indicates degree of development)
Carbonate nodules (secondary)
Manganese and iron coated gypsum nodules
Secondary gypsum
Gypsum nodules
Silcrete nodules
Alunite
Irregular curved fractures, often slickensided
Layer of sulphide or iron and manganese oxide
SEDIMENTARY STRUCTURES
Horizontally laminated
Cross laminated
Very small scale (sets <1cm thick)
Small scale (sets 1cm—5cm thick)
Medium scale (sets 5cm—0.5m thick)
Large scale (sets >0.5m thick)
Burrows, burrowed contact, trace fossils
Bedding planes
Flat/wavy — Sharp bedding plane
Flat/wavy — Transition <1cm
Intraformational clasts
Silcrete, limestone clasts
FOSSILS
Charophytes
Spores and pollen
Algal stems
Vertebrates (other than fish)—aquatic or terrestrial
Fish bones
Gastropods
Land snails
Ostracods
Aboriginal artifacts
Emu egg shell
CLAY MINERALOGY
S = smectite
RI = randomly interstratified clays
M = mica/illite
K = kaolinite
ELECTRIC LOGS
SP = self potential
R = point resistivity
74—1063 Del. T.S
R.A. Callen
S.A. Dept. of Mines

Fig. 2. Legend.

LITHOLOGY

NAMBA FORMATION (Derivation, Lake Namba*, CURNAMONA map sheet. "Namba" is the Jadliaura aboriginl tribal word for bone-fish).

The type section is Yalkalpo No. 1 bore (section 12, Fig. 3) drilled by the South Australian Department of Mines. Though not typical in some respects, this is the only section demonstrating the relationship to the Eyre Formation (Appendix 1). The sequence is of reduced thickness (56.60 m) compared with that of the reference section in Wooltana No. 1 bore (170.09 m, Section 11, and Appendix 1, excluding unit 4 which is 68.26 m thick). Section 11 also contains a microflora important in the age determination of the unit. The most extensive outcrops are on the west shore of Lake Tarkarooloo* (Fig. 14), where 26 m are exposed, and at the south and north ends of Lake Namba (e.g. Section 8, Fig. 15). These are unsuitable for designation as type sections, as only the uppermost beds are represented.

The type section consists of a series of cyclic sand/clay sequences in the lower part totalling 32 m of interbedded yellowish silt and dark grey or olive clay. This is overlain by 24.8 m of burrowed yellowish silt and intraformationally brecciated light olive clay. The cyclic sequences constitute the following, from the base of each set upwards:

(a) Fine to medium-grained sand with small to medium scale cross stratification.

(b) Laminated silt to very fine sand with very small scale cross-lamination.

(c) A zone of dolomite or calcite patches or a bed of dolomite.

(d) A relatively thick dark grey clay with irregular shiny-surfaced fractures (skew planes of Brewer 1964) and scattered patches and wisps of fine to coarse sands, in which grains are polished.

In this sequence (a) and (b) may alternate, or either (a) or (b) may be absent. Unit 5 of the type section represents a relatively complete cycle:

1.70 m Alternating CLAY and SILT to SAND. Sand very fine grained moderately sorted, percentage increasing upwards. Grains very angular, with crystal faces developed on quartz. Becomes calcareous at top. Bedding lenticular, with sedimentary brecciation and possible burrowing activity. Obscure horizontal lamination at top. 7% carbonate grains, rare mica. Colour 5Y6/1 mottled 10YR6/6.

0.75 m SANDY CLAY. Vertically streaked transition zone from sand to clay. Fine sand forms streaks and patches in clay. Very poorly sorted medium silt, with modes in clay and very fine sand sizes.

4.10 m CLAY, black (5Y1/1) and tough, with characteristic irregular shiny-surfaced fractures, and streaks of white carbonate. Mottled with orange brown colours which suggest an irregular microstructure. Many brown patches have well defined straight boundaries, producing angular blocks with dendritic or patchy internal structure. Unoxidized clay in these blocks is greenish grey. Scattered patches of silt and very fine sand are present. Upper contact sharp, but disturbed, with partial mixing into overlying sand.

The burrowed silt is very finely laminated, but this is often disrupted by burrowing. Very fine sand sized material is the coarsest grain size encountered. Colours are mainly yellowish grey to yellowish-white for silt or light olive for clays, having a greasy lustre. Fractures do not reach the degree of development of comparable structures in the black clays of the lower part of the sequence.

The burrow structures are a few millimetres in diameter, containing convex-down lamellae usually less than 0.5 mm thick. They are irregular and often branch, tending to be concentrated in certain horizons. Many of the homogenized clays have a churned structure suggestive of bioturbation.

The top of unit 9 marks the last appearance of the tough black clays characteristic of the lower part of the formation (Fig. 4). Frequently alunite ($KAl_3(SO_4)_2(OH)_6$) is developed as lustrous white particles or patches within the clay at the top of this unit. Above unit 9, silts dominate over clay, and burrows (Fig. 9) are more common.

The outcrop at Lake Tarkarooloo (section 13, Fig. 14) is situated on the western cliff face, immediately north of the track-crossing, on the route from "Frome Downs" to Black Oak Bore. The lower part of the section is a few tens of metres south of this track. The two parts were correlated using continuously traced bedding planes, and levelled with an Abney hand level. The strata are essentially horizontal, as are those in the type section.

Notable features of this outcrop are the interbedded gypsum nodules in the upper part of the section, the presence of ostracode-bearing oolitic dolomite associated with palygorskite, burrowed fine sand beneath the upper clay-dolomite sequence, the finely laminated calcareous silt near the base of the sequence, and the sharp contact with the upper tough black clay. These features, particularly the last mentioned, are useful in correlation. In section 12, the petrophysical logs indicate the interval between units 12 and 13, which lacks core, is probably silcrete, calcrete or dolomite. The absence of palygorskite beneath it suggests it may not be dolomite (this clay mineral is invariably associated with dolomite elsewhere in the basin). A turtle shell fragment in unit 10 supports a lithological correlation with section 8, if the black clay and ?dolomite are also correlated, but this is not in agreement with the clay mineralogy. Section 13 shows the typical dolomite—palygorskite association, and trend towards illite domination in member two.

Typical of the Namba Formation outcrop are the brown chert nodules which cover the breakaway slopes, and black manganese oxide coating on the grains in sand beds. Microscopically, the chert nodules have structures indicative of shrinkage and formation from accretionary silica gel. The black stain is manganese. Both these secondary effects are localized, occurring in sands cropping out in the banks of stream valleys eroded in the Namba Formation, prior to the deposition of the

Figs 4–9. Older units. Examples of Namba Formation lithology. Scales in mm and cm. Core sections. Arrows point to top of section.

Fig. 4. Section 12, Yalkalpo 1 bore, 125.00 m. Core. Dark grey clay with streaks of carbonate, darker and lighter clay, and sand, some filling burrows or root holes. Vertical disposition of patches well-displayed. Represents swamp deposition or a lake deposit which has been subject to subaerial exposure. Centripetal orientation of streaks is result of expansion of clay as it enters the core barrel.

Fig. 5. Section 11, Wooltana 1 bore, 218.68 m. Section through core, showing upper contact of laminated dolomite bed. Shrinkage and cracking of the dolomite has occurred, allowing penetration of the semi-fluid overlying clayey lime (C). Represents chemical sedimentation in a lacustrine or marginal marine environment. Boundaries of carbonate fragments and laminae emphasized by inking.

Fig. 6. Section 11, Wooltana 1 bore, 58.72 m. Core. Calcareous claystone with numerous burrows infilled with green-grey clay. Irregular shrinkage crack (C) has been infilled with semi-liquid clay which carries carbonate particles. The clay-filled crack is itself burrowed, indicating genesis soon after deposition. Represents combined chemical and detrital deposition in a marginal marine lagoon or lacustrine environment, with burrowing organisms.

Fig. 7. Section 11, Wooltana 1 bore, 122.00 m. Core. Fine lamination with typical alternation of silt and sand. Very fine scale trough cross-lamination. Quiet water deposition (migrating ripples) in a tidal, lacustrine or floodplain environment.

Fig. 8. Wertaloona 1 bore, 152.00 m. Araldite peel of sectioned core. Typical example of small scale cross-lamination in medium grained sand, partly disrupted by burrowing in upper part. Clayey laminae alternate at base. Relief coincides with porosity, though affected by varying thickness of core across section. Cross bedding formed by ripple migration, in an offshore bar or channel.

Fig. 9. Section 12, Yalkalpo 1 bore, 22.61 m. Core. Top of bedding plane. Shows burrows along bedding plane, with concave internal lamination (L). Represents quiet water deposition with burrowing organisms.

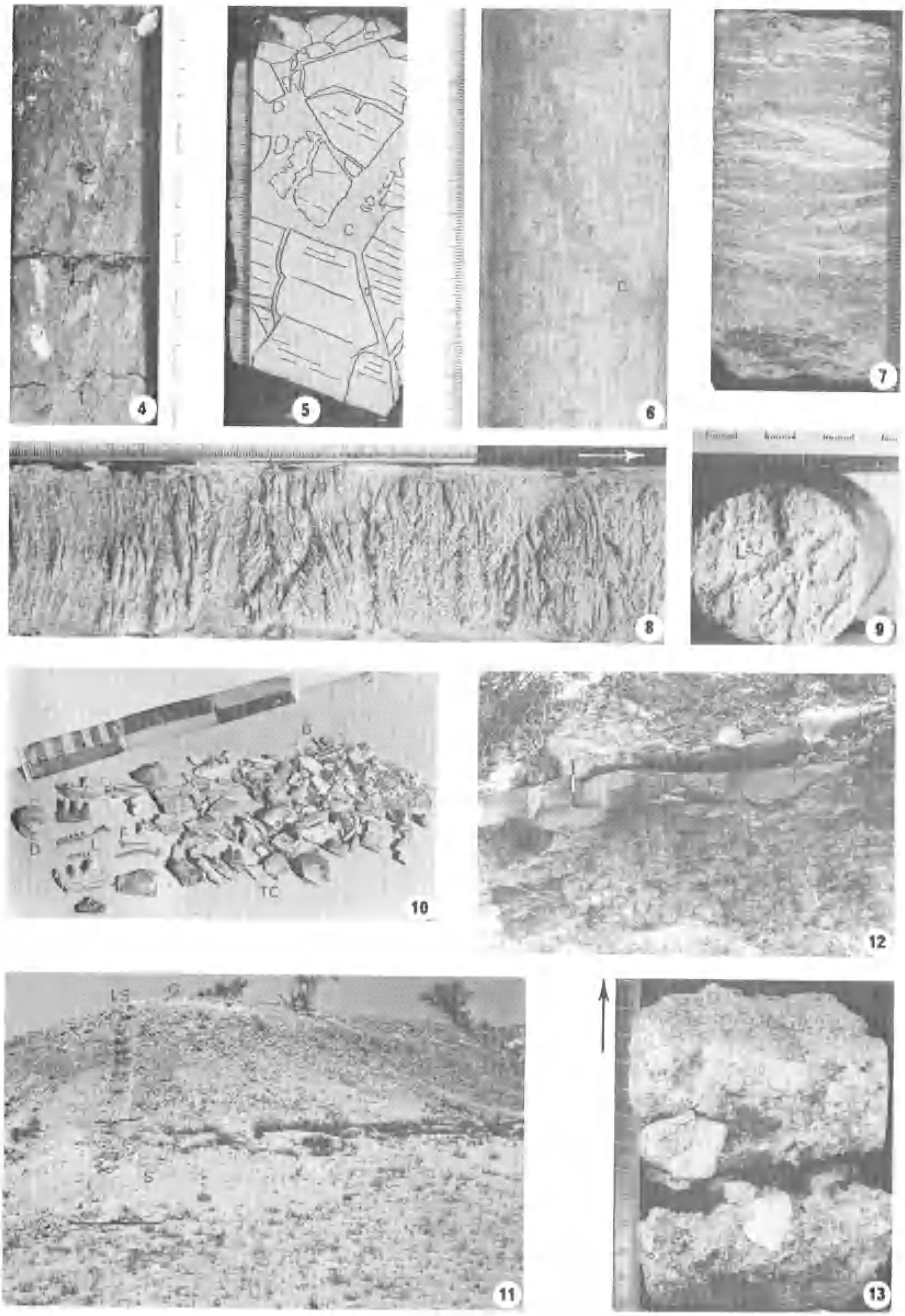
Figs 10–13. Outcrop of Namba Formation and Willawortina Formation, core of Willawortina Formation.

Fig. 10 Vertebrate fossil float from the Namba Formation of L.Yanda on Eurinilla Creek. Vertebra on far left (D) is riverine dolphin, on its right (L) are lungfish teeth and two fish spines (F). In centre (T,C) are mainly crocodile scutes and turtle plates. A fragment of bird bone (B) is on upper right corner. From base of upper unit of Namba Formation. Scale 30 cm.

Fig. 11. South end of Lake Namba. Typical outcrop of Namba Formation. Gypsum nodule capping (G) overlies thin nodular dolomite (white: LS). Greyish olive silty clay (grey) occupies most of section. Grassed white bench at base of slope is very fine grained laminated sand (S). 30 cm scale rests on upper contact in trench. Outcrop surface is covered by gypsum nodules and weathered clay. Sand represents channel or floodplain deposition, clay and dolomite probably lacustrine.

Fig. 12. Balcanoona Ck, Willawortina Formation. Calcified medium crossbedded sand lens in calcareous reddish brown very poorly sorted clay-silt. Note thin bedding in silt. Sand lens represents deposition from higher powered streams, fine sediments are floodplain deposits. Scale 30 cm.

Fig. 13. Section 10, WC2 bore, 68.75 m, section of core. Willawortina Formation shows large pebbles, granules, very coarse silty and clayey sand. Extremely poor sorting. Represents deposition in an alluvial fan environment. Scale in mm.


4
D
C
5
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8
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D
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TC
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12
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13

Millyera Formation and *Eurinilla Formation* (new names see Pt. II).

Wooltana No. 1 bore (Fig. 3, Section 11 and Appendix 1), drilled by the Australian Department of Mines is an important supplementary section, exhibiting a thicker sequence, lithologically more typical of the Namba Formation than the type section. It also demonstrates the intertonguing relationship with the *Willawortina Formation* (new name Pt. 1).

The base of the Namba Formation was not penetrated, though cuttings from old Pootana bore (Fig. 1, 50 km north-north-east of Wooltana No. 1 bore) indicate a total thickness of 190 m. This compares with 54.40 m in Yalkalpo No. 1 bore (Section 12). The sediments have been divided into six informal units. The lowest of these (unit 1) consists of 8.5 m of laminated black and dark olive carbonaceous clays with characteristic fauna and microflora (discussed later). Laminae containing ostracodes of early Neogene aspect (including cypridids—pers. comm. K. McKenzie 1973), and fish spines are present. Protoconchs of a small gastropod (*Potamopyrgus* s.l., see Ludbrook 1972)[5], are scattered through the clay and ?gastropod tracks and burrows of other organisms are common on bedding planes. These sediments are restricted to the Poontana Sub Basin west of Lake Frome.

Unit 2 (40 m) is dominated by white, frequently oolitic, dolomite beds (Fig. 5) containing characteristic branching pores 0.5 mm diameter, alternating with clay, and sometimes interbedded with silt and fine sand. The carbonates have unusual transitional or irregular upper boundries: in some beds spherical zones delineated by colour variations develop, which pass upwards into discrete carbonate lumps within the matrix of overlying unit. These are thought to be diagenetic features associated with lithification possibly resulting from intermittent exposure. Other beds (Fig. 5) show shrinkage cracks, into which the overlying clay penetrates. Particles of carbonate are included and flow lines occur, indicating liquefaction resulting from thixotropic transformation. The lack of rounding of the clasts derived from cracking, and gradation to uncracked material, suggests sinking of carbonate plates into underlying liquid clay. The cracking may be a syneresis phenomena, which occurred during or shortly after deposition of the overlying clay. Occasionally the clasts have been rounded, and incorporated in the overlying unit: current or wave action has been effective in some cases. Other beds show wispy carbonate and clay intermixed at the contact, interpreted as flame structures which have transformed by thixotropic changes, to flow as a semi-liquid. Bioturbation is frequently associated with these structures, and is common throughout (Fig. 6).

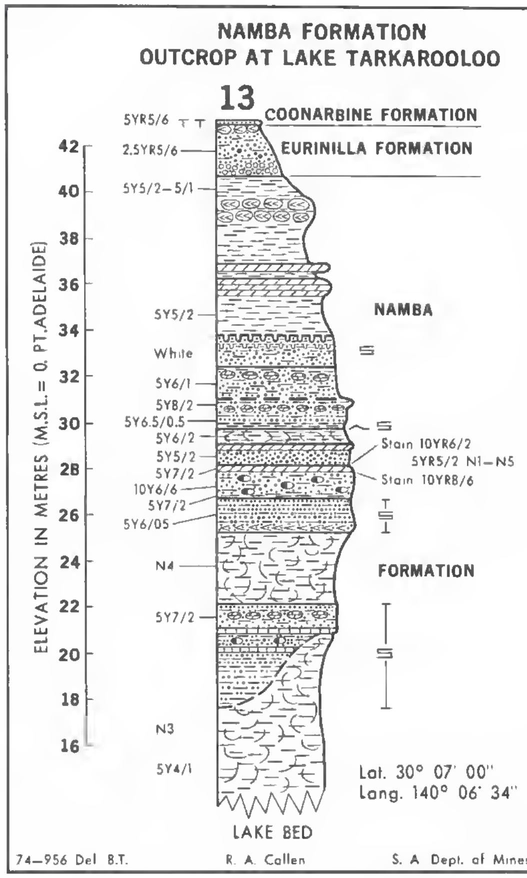

Fig. 14. Namba Formation—outcrop reference section.

Unit 3 (49.7 m) is very similar to the lower part of the Type Section (section 12, units 1–9), exhibiting similar cyclic deposition, in which cross-stratified sands (Fig. 8) grade up into tough black clays with pockets of medium sand, often with polished grains (see description of unit 4, section 12). The black clays are identical to those in section 13, Fig. 14. Analyses showed the black colour does not

[5] Ludbrook, N. H. (1972). Age and environment of deposition of a sample from Yalkalpo No. 1 Bore, Lake Frome area, South Australia. *S. Aust. Dept. Mines Rept.* RB 72/207 unpub.

result from anomalous concentration of carbonaceous matter, sulphides or manganese. Iron-rich montmorillonite or humic acid staining are alternative explanations. A bed of dolomite or limestone nodules is often present at the contact between the sand and black clay. Lamination (Fig. 7) is generally not as prominent as in the equivalent strata in the type section, and the sand beds are often burrowed.

The cross-bedded sand sequence of unit 4 (49.2 m total thickness) grades up into a uniform olive clay with churned structure. The sand bed is a prominent horizon west of Lake Frome, and is being prospected for sedimentary uranium of the geochemical cell type. The dark sandy clays with skew planes are rather weakly developed in this unit.

The upper carbonate horizon, unit 5, is 23.7 m thick, has a much higher proportion of clay than unit 2, and is intensely burrowed. Sedimentary gypsum laminae are present.

The uppermost part of the section (unit 6) in which the Namba and Willawortina Formations intertongue is more conveniently described when discussing relationships between units.

The Namba Formation has been broadly divided into two informal members (1 and 2) of regional extent, on the basis of the presence or absence of the tough black sandy clays with skew planes. The lower member (e.g. units 1–4, section 11, Fig. 3) is characterized by these clays, and cyclicity is more prominent. It was later found that this subdivision closely coincided with the change from smectite to illite-kaolinite dominated clay mineral suites (inset, Fig. 3), except in Yalkalpo 1 bore (Fig. 3, section 12). In this bore it is uncertain whether the dominance of smectite throughout the sequence represents a local variation in clay mineralogy or whether the upper part has been wrongly assigned to member 2 (which may have been eroded). The mineralogy in Yalkalpo 1 bore is remarkably uniform, smectite almost the only component. The higher proportion of silt is also unusual.

An interesting, varied vertebrate fauna is found in the upper part of member 1 and the base of member 2 of the Namba Formation in various small saltpans southeast of Lake Frome, in the vicinity of Eurinilla and Billeroo Creeks. One of these localities is at Lake Pinpa (Section 8, Fig. 15).

WILLAWORTINA FORMATION (Derivation—Willawortina Creek, passing south of "Wertaloona" on the Balcanoona High Plains, in the vicinity of the outcrop reference section).

The type section for this unit is Western Nuclear's sedimentary uranium test hole WC2 (Fig. 3, section 10 and Appendix 1) cored from 8 m to base. The hole was drilled on the uplifted plains flanking the Flinders Ranges, near Paralana, where a continuous sequence of coarse poorly sorted sediments is encountered. A detailed division is not possible as a result of moderate recovery and gradational contacts. Three members are recognized, members 1 and 2 (16.4 m and 17.0 m thick respectively) have less mica and sand in the matrix than the overlying beds, and are less oxidized. Member 2 has finer overall grain size than member 3 but is comparatively coarser than member one. Members 1 and 2 are equivalent to unit 6 of section 11.

Although bedding planes are very indistinct, transitions in grain size are often abrupt (Fig. 13). Secondary alteration with production of red mottling is common throughout. Feldspars are generally more abundant than in the Namba Formation. Sandy beds have matrix-supported framework with a high proportion of framework compared with the Namba Formation.

The Formation crops out along creeks incised into the high level plains flanking the Flinders Ranges, along the southern shore of Lake Frome, and along the Siccus-Pasmore River. The section (Fig. 3 section 1, Appendix 1) in a low range of hills, 3.7 km on 22°T, north of Prism Hill and south of "Wertaloona" (Air photo reference: S. Aust. Dept. Lands Svy. 803, *Balcanoona* Run 7, photo 0014), is an important supplementary section, as it is the only outcrop in which the contact with the Namba Formation can be observed. The sequence is 140 m thick and dips 30–50° east, in accord with the remainder of the Cainozoic section. The whole rests with angular unconformity on Middle Cambrian rocks. Exposure is moderate to poor, necessitating reconstruction from several scattered outcrops, particularly through the Namba Formation. This sequence was first mapped by Leeson (1967)[3] who referred the conglomerate to the Telford Gravel (Firman 1963, 1964, 1966b, 1967a, 1970) and the underlying clays to the Avondale Clay (Firman 1967a). Subsequently Callen (in Coats 1973) remapped the area during 1970–1 for the COPLEY 1:250 000 geological map sheet, and the sequence was assigned to an undifferentiated Tertiary-Quaternary unit.

Elsewhere on the eastern portion of COPLEY, green clay, now known to belong to the same sequence, was called Avondale Clay.

In Section 1 (Fig. 3) the base of the Willawortina Formation is placed at the base of the lowest conglomerate. Beds below this unit include poorly sorted sandy clays, but with interbedded micritic white dolomite, fine yellow-green sand, and pale grey and olive clay, closely resembling the Namba Formation. Below these beds, resting with angular unconformity on the gently folded Middle Cambrian red beds, is coarse sand with polished pebbles and ?ferricrete clasts resembling the Eyre Formation.

Another section regarded as equivalent to the Willawortina Formation, but of overall finer grainsize, is exhibited by unit 6 of Wooltana No. 1 bore (Fig. 3, section 11). It shows a prominent alternation of sand and clay in fining upwards sequences, each separated by sharp contacts. Sorting is uniformly very poor, and mottled green and brown colours common. Secondary carbonate nodules are present, and also beds of lacustrine dolomite. Toward the top of the section the fining upwards sequences become poorly defined. The top is capped by a thin dolomite bed, overlain by cobble conglomerate and sandy clay silt, representing the Eurinilla Formation and "unnamed conglomerate" (probably equivalent to the Millyera Formation).

Upstream from section 2 along Balcanoona Creek, excellent exposures (e.g. Fig. 12) of the upper part of the sequence seen in section 11 are displayed in cliffs. One of these exhibits a hiatus—limestone and conglomerate in the lower part have been faulted before deposition of the overlying silts. Subsurface (below soil) karst structure is present.

RELATIONSHIPS BETWEEN FORMATIONS

The nature of the contact between the Namba and Eyre Formations, and difficulties associated with differentiation when both units are sandy, have been discussed by Wopfner *et al* (1974). The disconformable relationship is demonstrated palynologically by W. K. Harris (pers. comm. 1974, see section on AGE, this paper).

The intertonguing relationship between the Willawortina and Namba Formations is illustrated by Fig. 3 (inset), a section across the Paralana High Plain, on which Wooltana 1 bore has been superimposed. A similar section showing the same features can be drawn across the Balcanoona High Plain through WT3, WT5 and WT4 bores (Mines Administration Pty Ltd) and Wooltana 1 bore. The decrease in coarse clastics proceeding east from the Flinders Ranges is demonstrated. The lower boundary of the Willawortina Formation has been drawn at the base of the characteristic mottled, immature, poorly sorted sediments. Note the varying electric log response to similar lithological differences between bores, which results from differing drilling mud properties and sensitivity, and in the case of WC2 bore, different instrumentation. Holes F22–20 and E20–13 however, are not affected by these variables and are directly comparable.

In Wooltana 1 bore (section 11 Fig. 3) intertonguing with the Namba Formation is exhibited by unit 6. The typical Namba Formation lithology of sharply differentiated relatively better sorted clay and silt beds grades to the extremely to very poorly sorted coarse grained Willawortina Formation. The two units alternate to some extent. Essentially there is a gradual upward increase in the coarser grained fraction, though an isolated pebbly bed appears low in the sequence. Clays are rich in illite (muscovite) and feldspar is abundant, compared with the bulk of the Namba Formation where these minerals are minor components and smectite the dominant clay mineral.

Unit 6 of section 11 is therefore interpreted as the equivalent of the lower part of the Willawortina Formation in section 10, a relationship suggested by the correlation lines drawn in Fig. 2 of Callen (1976). The criteria chosen here to identify the base of the Willawortina Formation are those readily mappable: the base of the consistently coarse-grained poorly sorted sediments. Thus unit 6 as shown on Fig. 3 is regarded as mainly Willawortina Formation, though it contains tongues of lacustrine dolomite like those in the Namba Formation. The contact is readily recognizable from petrophysical logs (Callen 1976 Fig. 2) and can partly be explained by the degree of secondary alteration (carbonate nodules, iron oxide mottling) stratigraphically associated with the Willawortina Formation. These secondary effects alternated with deposition, and are an integral part of the unit.

Support for the intertonguing relationship between Namba and Willawortina Formation is also derived from clay mineral analyses (Callen 1976)[2]. Results are shown diagrammatically on the inset of Fig. 3 demonstrating the abrupt change from rocks dominated by smectite and randomly interstratified clay, to illite (largely well crystallized muscovite), randomly interstratified clay and kaolinite. This change corresponds to the position of the alunite horizon within the Namba Formation, and is widespread throughout the basin, having been located in 14 bores and in outcrop. The change was probably initiated by uplift of the Flinders Ranges, probably with climatic variation from high to low rainfall as indicated by clay mineralogy and colour change (see later). It is therefore regarded as an approximate time marker, and is coincident with the boundary between members 1 and 2 of the Namba Formation, and with the base of the Willawortina Formation in its type section. The change corresponds with the base of the Willawortina Formation identified in WC2 and Wooltana 1 bore.

Alunite is recorded near the top of member 1 of the Namba Formation, forming a series of nodular horizons associated with sharp bedding planes. The nodules ramify through the clay and resemble calcareous hardpans of soils in their manner of development. The horizons are widely developed in the Paralana High Plains area, but are also found in the eastern part of the basin in C15 bore. Here, they are overlain by a relatively thicker sequence of member 2 than in the high plains. The horizons are regarded as soils, associated with a well developed hiatus or disconformity formed during uplift of member 1. This emphasizes the time significance of the clay mineral change recorded earlier.

Silcrete has been identified by one author (R.A.C.) in the interval 72–94 m from cuttings of bore LB12, drilled by Mines Administration Pty Ltd. It is developed on clay, and overlain by greenish-red mottled sandy calcareous clay resembling the Willawortina Formation. A number of closely spaced bores between "Murnpeowie" and Reedy Springs, drilled by Pechiney Exploration (Australia) Pty Ltd (Mannoni & Barral 1972)[6] suggests a similar relationship. The silcrete varies from the red and grey mottled chalcedonic and opaline "puddingstone" to the grey microcrystalline quartz "grey billy" type, according to whether clay or sand is silicified. This is displayed by Mannoni & Barral in their cross-section, and can be observed in outcrop. The same silcrete horizon forms a cap to the dipping Eyre Formation at Reedy Springs (Wopfner *et al.* 1974 Fig. 2). The silcrete is thought to represent a soil horizon, and therefore marks a disconformity (Callen 1976)[2].

Thus there is evidence supporting a disconformity between the Namba Formation and rocks resembling the Willawortina Formation in this area. Although the silcrete has not been identified in the high plains regions, it is apparent that the Willawortina Formation, as defined, may contain some younger material.

The brown silcrete and ferruginous material developed on sandy facies of the Namba Formation exposed at Lake Tarkarooloo, and around other saltpans east of Lake Frome, are thought to be equivalent to that just described. Cementation certainly occurred prior to deposition of the Millyera Formation, as indicated by abundant silcrete nodules and ferruginized Namba Formation clasts in the base of the channel facies in Lake Tarkarooloo.

AGE

The flora of member 1 of section 11 (Fig. 3) indicates an early to middle Miocene age for the base of the Namba Formation (Batesfordian-Balcombian—pers. comm. W. K. Harris 1974). Harris states the flora is similar to that of the Munno Para Clay of Lindsay & Shepherd (1966), and Lindsay (1969, p. 38) in the Adelaide Plains Sub-Basin. An assemblage of the same age was found in Mines Administration Pty Ltd LC1A bore (for lithological description see Wopfner *et al.* 1974) to the north of section 11, and also in Lake Eyre 20 bore (Johns & Ludbrook 1963) in the Etadunna Formation.

The age of the Willawortina Formation, accepting a conformable relationship with the Namba Formation, is therefore medial Miocene or younger. Its upper age limit, as for the Namba Formation, is deduced from relationship to the Millyera Formation, and Eurinilla Formation (Pt II) indicating a minimum age in excess of 40 000 years B.P., possibly pre-Pliocene.

[6] Mannoni, N., & Barral, J. M. (1972).—Murnpeowie Project S.M.L. 373 (South Australia) drilling program report R/72-21-U. *S. Aust. Dept. Mines envelope* 1327. Unpub.

TABLE 1. SUMMARY OF ROCK UNIT PROPERTIES

ROCK UNIT	SECTION (Fig. 3)	LITHOLOGY	SEDIMENTARY STRUCTURES	CRITERIA FOR CORRELATION	FOSSILS	AGE	GEOMETRY	GEOMORPHIC EXPRESSION	ASSOCIATED SOILS
WILLAWORTINA FORMATION	10 (1, 11)	Extremely to very poorly sorted bouldery to pebbly silt clay with numerous greenish carbonate nodules enveloping matrix and skeleton grains in southern areas. Lenses and sheets of pale greenish white dolomite with scattered pebbles, bouldery dolomite near ranges. Lenses of pebbles to large boulders common near Flinders Ranges, sand beds further east 2.5-7YR3-8/1 8. 5-7Y6-8/1-8.	Crude wavy and lenticular horizontal lamination. Well defined medium scale cross-beds, Beds ½—4m thick. Fining upwards cycles in lower part, finer facies.	Greenish clays with very poorly sorted sand to boulder content, usually matrix supported framework. Greenish silty carbonates. Red brown mottling common.	Rare vertebrates.	LATE MIOCENE-PLIOCENE possibly to EARLY PLEISTOCENE (from relationship to NAMBA FORMATION)	Wedge shapes mass, thinning east, between Lake Frome and Flinders Ranges, and to south 0 — 150m	Forms basic landscape of uplifted "high plain" flanking Flinders Ranges, where it supports growth of *Eucalyptus gillii* Crops out as vertical or overhanging cliffs along creeks. Cliffs along Siccus Pasmore Rivers and along south shore of Lake Frome.	Well developed massive white hard carbonate developed in long cylindroids or horizontal sheets, pisolitic structures. Hard butt groundwater calcrete cements porous sediment. Massive crusts of gypsum rosettes. Red green mottling, green colour increasing with depth, black patch stain on fractures.
NAMBA FORMATION	12 (11)	Alternating fine to medium poorly sorted sands, silt and clay, thin dolomite and limy dolomite beds, often oolitic. Sands generally angular of high sphericity. Clays may be black (ferrous ion) and tough with characteristic irregular shiny-surfaced fractures, or pale green or grey. Sands and clays may be carbonaceous. Dolomites often have nodular structure, and are penetrated by branching pores lined with manganese. Rare Charales limestone. 1 10Y2 9/0.25 6 N0 N9, 10YR2 7/1 2, rarely 5B5 7/1, 5-10R3-3.5/3-4, 5GY4-7/0.5-1 and 5G6/1	Horizontal lamination common, especially in silt and very fine sand. Very small to medium scale cross-bedding common in silts and sands. Irregular ooliths in carbonates, often rod shaped. Intraformational brecciation, quick flow structures common. Bioturbation common. Rare shrinkage (?subaqueous) cracks and slumps. Cyclic deposition prominent.	Pale grey green clays and fine silts and sands, dolomites, tough black clay with irregular fractures. Fish spines in lower beds. Vertebrates—lung fish teeth.	Ostracoda (Cyprididae), Charales oogonia and stem moulds. *Potamopyrgus* s.l., Dipnoi, Teleosti, Chelonia Crocodilia, Aves, Monotremata, Marsupialia, Cetacea. Plant spores — *Nothofagus*, *Dacrydium*, *Podocarpus*, *Eucalyptus*, Gramineae, Restionaceae, Casuarinaceae, *Pediastrum*	MEDIAL MIOCENE (BATESFORDIAN-BALCOMBIAN) from plant spores and pollen.	Thin widespread blanket and shallow basins 20 — 250m	Sloping cliffs often capped by dolomite, gypcrete or secondarily carbonate cemented younger units, along edges of dry lakes and creeks, east and south-east of Lake Frome. Less commonly as dipping sequences upfaulted along western margin of Flinders Ranges. Mainly subsurface	Sometimes capped by ferruginous yellow brown orthoquartzite silcrete. Alunite soil like horizons associated with uppermost black clay.

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REGIONAL CORRELATION

Relationships with other units used on adjacent South Australian Department of Mines Geological Atlas Series map sheets (COPLEY, PARACHILNA) and in other basins, are shown in Table 2.

Equivalence between the Etadunna and Namba Formations is demonstrated by lithological similarity, similar flora, and occurrence of species of fossil marsupials previously known only from the Etadunna Formation. Both contain the unusual dolomite-palygorskite mineral assemblage.

A sequence penetrated during drilling operations by Carpentaria Exploration Pty Ltd immediately west of the Ediacara Fault (Binks 1972) is very similar to that encountered in Wooltana No. 1 bore (section 11, Fig. 3) in the Lake Frome area. The section in Binks' Fig. 3 has been interpreted by one of us (R.A.C.) thus: 0.0 to 94.8 m ?Willawortina Formation equivalent, 94.8 to 121.0 m—unnamed beds, 121.0 to 233.2 m—Etadunna Formation equivalent, 233.2 to 298.7 m—Eyre Formation. The sequences in the intermontane Walloway and Willochra Basins (Howchin 1909, 1913; O'Driscoll 1956) are more difficult to compare lithologically, but palynology (Harris 1970)[7] from 30 m in Willochra No. 2 bore suggests most of the sequence is equivalent to the Eyre Formation.

On the northwestern side of the Flinders Ranges is the Avondale Clay (Firman 1967a) of similar lithology and mineralogy to the green clays of the Namba Formation and Willawortina Formation, particularly where they intertongue (unit 6, section 11, Fig. 3). The type section is affected by secondary iron oxide mottling, and the "clay" is actually a clayey fine sand, with angular shiny grains. The relationship between Avondale Clay and Etadunna Formation is unknown at the type area: the base is not exposed, and the unit is unconformably overlain by the Telford Gravel and "Conglomerate at Lyndhurst" (Firman 1969). The "Conglomerate at Lyndhurst" resembles conglomerates in the Willawortina Formation (Fig. 12 this paper). Kaolinite is the dominant clay in the Avondale Clay type section, and is abundant in the upper part of the Namba Formation, and the Willawortina Formation.

A section of Yerila Creek in the Mooloowatana area of the northern Flinders Ranges was described and figured by Firman (1971, Fig. 12)[8] as Avondale Clay. Upstream from this site, a lower part of the section is exposed, connected by continuous outcrop. This exhibits micritic carbonate nodules, underlain by silty olive grey clays similar to the upper part of the section. The clay is capped by a well-developed hard white fine grained carbonate soil horizon, comparable to that developed on the Willawortina Formation at Balcanoona Creek. It is overlain by the Eurinilla Formation. The lithology is identical to the transition beds between the Namba and Willawortina Formations (section 11, unit 4).

The Avondale Clay is regarded by Firman as much younger than the Etadunna Formation, hence younger than the Namba Formation. However, the comments above suggest it could either be part of the Etadunna Formation, equivalent to the lower part of the Willawortina Formation or upper Namba Formation.

The lower part of the Telford Gravel (Firman 1967a) may be equivalent to at least part of the Willawortina Formation.

ENVIRONMENT

Consideration as to whether the Namba Formation sediments are marine, marginal, or non-marine was a prime objective. The most conclusive indicators of marine influence are marine fossils and glauconite, hence samples were investigated for foraminifera, and any green pellets or clays were studied by x-ray diffraction. A variety of lithological types from subsurface and outcrop were examined by J. M. Lindsay who found no foraminifera. Non-marine gastropods and pelecypods (pers. comm. N. H. Ludbrook 1973–4) are present, as are non-marine ostracodes (pers. comm. K. McKenzie) and the fresh water algae *Pediastrum* (pers. comm. W. K. Harris) and charophytes. All green clays proved to be montmorillonite, and green pellets found in the eastern areas were dolomite, associated with non-marine pelecypods.

Other evidence for non-marine origin is derived from the terrestrial vertebrate remains (e.g. Fig. 10). Several skeletons were found in a partly articulated state. Delicate bones are

[7] Harris, W. K. (1970).—Palynology of Lower Tertiary sediments, South Australia. M.Sc. thesis, University of Adelaide (unpublished).

[8] Firman, J. B. (1971).—Regional stratigraphy of surficial deposits in the Great Artesian Basin and Frome Embayment in South Australia. *S. Aust. Dept. Mines Rept.* RB 71/16.

TABLE 2 CORRELATION CHART – OLDER UNITS

TIME / UNIT	LAKE FROME AREA: CALLEN & TEDFORD, This paper	SUGGESTED EQUIVALENTS – ADJACENT MAP SHEETS AND OTHER BASINS: FIRMAN, N. Western Flinders Ranges	COATS et al. COPLEY 1:250 000 map sheet	WOPFNER, 1974, Strzelecki Desert and northeastern South Australia	STIRTON et al., 1961 Lake Eyre
LATE MIOCENE to EARLY PLEISTOCENE	Ferricrete	Ferruginous horizon (of Karaanda surface)	BUNGUNNIA LIMESTONE equivalent; Conglomerates, clays "T—Q"		
	WILLAWORTINA FORMATION	AVONDALE CLAY and "Conglomerate at Lyndhurst"	AVONDALE CLAY		MAMPUWORDU SAND; WIPAJIRI FORMATION
	? Puddingstone and grey billy silcrete, an ferricrete ?	FERRICRETE			
MEDIAL to LATE MIOCENE	NAMBA FORMATION			ALBERGA LIMESTONE; DOONBARA FORMATION	ETADUNNA FORMATION
OLIGOCENE to EARLY MIOCENE	Massive columnar "grey billy" silcrete	SILCRETE		SILCRETE OF CORDILLO SURFACE	
MEDIAL EOCENE AND PALEOCENE	EYRE FORMATION		EYRE FORMATION		EYRE FORMATION

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well-preserved, and abrasion due to transportation in currents virtually absent. The sediments in which they occur are fine sand, clay, and dolomitic clay. A nearshore marine environment therefore seems untenable, though a lagoonal or upper estuarine environment is possible. A non-marine environment is preferred, though presence of Cetacean remains (a platanistid dolphin) indicates a link to the sea at some stage.

More specifically, environments are (i) Micritic dolomitic carbonates with irregular ooliths, suggesting low energy shallow lake or shoreline conditions. (ii) Black, laminated fossiliferous clay of Wooltana No. 1, unit 1, suggesting a well developed lake: the fine laminae resemble varves, but have been disrupted by diagenesis and bioturbation. (iii) Sedimentary structure types, abundance of fines, and very poor to poor sorting support a low energy environment for the whole unit. This may explain the apparent lack of well-developed beach sands, which would be poorly developed and poorly sorted along a low energy shoreline.

The environments represented by the cyclic sequence described earlier are in ascending order: (a) channels: small to medium scale cross-bedded fine to medium sand (Fig. 8), (b) flood plain, estuarine or lacustrine: finely laminated silt, often burrowed and with very small to small scale cross-bedding (Fig. 7), and olive clay, (c) lacustrine: patchy carbonate, oolitic dolomite (Fig. 5) and clay (Fig. 6), (d) swamp or mud flat with occasional channels: hard, black, mottled clays with irregular fractures and sand patches (Fig. 4), interpreted as vertisols. The cyclic sequences are of 1–20 m thickness, averaging 9 m, well-developed in most parts of the basin, except the northwest where uniform clay sections dominate. The cyclicity suggests a depositional process resulting in a particular sequence of facies, but with inherent instability. Some examples applicable to the Namba Formation are (1) a delta building into a shallow lake or estuary (necessarily shallow because the cyclic sequences are thin), (2) repetitive transgression and regression of a shallow lake shore in response to fluctuations in water level (3) repetitive avulsion of a meandering stream, (4) bars associated with development and abandnoment of portions of river channel.

The abundant bioturbation, and its occurrence in medium-scale cross-bedded coarse channel sands, and basal parts of laminated silt beds, is inconsistent with river channel origin of these facies. These sands more likely represent offshore lacustrine bars. Lenses of the coarser sand facies at the base of, or within, the tough dark grey clays are also difficult to explain in terms of a river and flood plain relationship: channels cutting across a tidal or deltaic mud-flat are more acceptable. Subsequent intensive bioturbation or rheotropic flow has partly destroyed bedding, distributing the sand in irregular patches. In the estuarine case, the absence of any evidence for a marine influence, particularly in the microfauna, indicates deposition in the uppermost reaches of the estuary. In sequences where coarser channel sands are interbedded with non-burrowed laminated silts, the river-channel and flood-plain relationship is still applicable.

Fluviatile deposits are abundant, and fossils (e.g. Fig. 10) of aquatic vertebrates (Dipnoi, Teleostei, Chelonia, Cetacea) suggests a permanent water supply, and fossil plants (*Nothofagus* and *Podocarpus*) indicate high rainfall. The distribution of lenses of channel sands within an essentially clayey sequence is typical of meandering rivers. Although only 42 current directions were measured (mostly in the Lake Tarkarooloo area) results suggest a southerly component of transport direction for the upper part of the Namba Formation, in marked contrast with the north-easterly direction of overlying units.

Dense vegetation is suggested by the palynology of the basal unit 1: the modern descendants of the species represented typify rainforests. Abundant grass pollen are evidence that grassland occupied extensive areas. Thus rainforest was not continuous in the early lacustrine phase of deposition. The relative abundance of arboreal marsupials in the upper part of the Namba Formation indicates the presence of gallery forests along the water-courses.

Apparently at variance is the smectite—dolomite—palygorskite association, frequently recorded from arid soils, playa lakes and warm hypersaline waters (e.g. McLean *et al.* 1972, Bentor *et al.* 1963, Meester 1971, Singer *et al.* 1972). At present dolomites and high-Mg calcite are forming in hot arid or semi-arid hypersaline lagoons (e.g. Von der Borch 1965, Von der Borch *et al.* 1975, Friedman *et al.* 1973) though some magnesium-rich sediments are found in latitudes as high as 48°N (Muller *et al.* 1972).

Millot (1964) indicates the montmorillonite—palygorskite—sepiolite association is the result of offshore lacustrine or marine chemical deposition. This took place adjacent to a lateritized land mass of low relief and dense vegetational cover, in a subtropical or tropical climate. Sepiolite is absent in the Lake Frome area, but this may be an affect of degree rather than basic difference. The hypothesis as applied to the Namba Formation overcomes the difficulty of evoking evaporative conditions in a high rainfall climate.

Millot's hypothesis has been applied in a similar manner to the Cainozoic rocks of the Jordon Valley (Wiersma 1970). These sediments contain a remarkably similar sequence of clays to the Namba Formation. Particularly relevant are Wiersma's comments regarding the origin of palygorskite (p. 88). He concluded that intensive weathering on the hinterland under warm humid conditions was necessary for liberation of the elements essential to the genesis of palygorskite and its associated sediments, and that evaporation in the sedimentation basin should be such annually as to provide the necessary concentration of chemical elements. He deduced that evaporation must prevail over precipitation and fluviatile and/or marine supply of water to the basin. In many places in the present tropics evaporation can exceed annual precipitation, with resultant formation of evaporites in favourable locations. Palygorskite was of detrital origin in the late Tertiary and Quaternary of the Jordon Valley, having been derived from Cretaceous and early Tertiary rocks in which it originated by chemical sedimentation. In the Lake Frome area no preexisting rocks rich in palygorskite were present: rather kaolinite, smectite and illite are abundant. Palygorskite can be formed in soils (Singer & Norrish 1974) but only in relatively low proportion, thus it must have originated within the depositionary basin during sedimentation.

It is notable that Millot's (1964) ideas as applied to deposition of Namba Formation sediments require an equivalent Miocene lateritization on adjacent land masses. In this context Wopfner's (1974) conclusions regarding an Oligocene-Miocene "ferralitization" are of interest. Although the evidence he gives for age of the Doonbara Formation is inconclusive, some additional observation are made here. Firstly clasts identified with the Doonbara Formation (by R.H.T.) are found in the Wipajiri Formation (Stirton *et al.* 1967) of Miocene age. Secondly the ferruginization in Lake Eyre Bore 20, doubtfully equivalent to the Doonbara Formation, is recorded by Callen (Wopfner *et al.* 1974, Fig. 17) *within* the lower part of the Miocene Etadunna Formation. Others have also recorded an older Tertiary ferricrete (Firman 1967b). Therefore lateritization (or at least, ferruginization) could have been proceeding in uplands adjacent to the basins in which the Etadunna Formation and Namba Formation sediments were being deposited.

The main carbonate horizons occur a few metres above unit 1 of section 11, with its rainforest flora, and above the vertebrate zone with its indications of seasonal climate with abundant water supply. The presence of these carbonates can be explained in terms of protracted arid phases superimposed on a subtropical or warm temperate climate.

In addition the presence of detrital feldspars must be explained, particularly in view of the abundance of plagioclase and association with smectite.[8] The possibility of addition of volcanic material from eastern Australian must be considered, the Miocene being a period of maximum vulcanism (Sutherland *et al.* 1973). However, the percentage of feldspar is not large. Preliminary studies of feldspars in the Namba and Willawortina Formations suggest relative proportions of feldspar types and compositions of plagioclases are similar to an unmodified contribution from nearby Precambrian crystalline basement rocks. On present evidence there is apparently no change in relative abundance and type of feldspars in the illite-kaolinite rich zones of the Tertiary, in comparison with the smectite zones. This suggests abundance is not tied to smectite occurrence, as would be expected if these minerals originated from volcanic ash falls. The presence of feldspar presents a problem considering the evidence for a humid climate. Possibly seasonal aridity and nearby source permitted preservation. In addition Todd (1968) has shown plagioclase is more stable than orthoclase under conditions of restricted leaching, in a tropical climate. Thus smectite (montmorillonite) is unlikely to have originated from volcanic ash falls.

[8] The mineral group smectite, but R. N. Brown recognized dioctahedral montmorillonite in several instances.

In the final analysis, the Namba Formation was thought to be deposited in a warm temperate to subtropical climate. The landscape had a savannah aspect, with gallery forests around permanent rivers and lakes. Periods of aridity occurred.

High average temperature, invoked to explain the mineralogy of the Namba Formation, is in accordance with marine paleotemperature measurements in southern Australia (Gill 1968) and New Zealand (Devereux 1968, Jenkins 1968) of 18-22°C for the Miocene. Considered in the light of continental drift data, which suggest Australia was closer to Antartica (though drifting rapidy northward: Wellman *et al.* 1969), and data which indicate the cooling of Antarctica was underway (Hayes *et al.* 1973), the temperature can be explained in terms of greatly expanded subtropical climatic zones during early and middle Miocene times.

Deposition of the Namba Formation in the central part of the Lake Frome area was followed by widespread ferruginization and silicification (opal, and quartz overgrowths) and development of cryptocrystalline silica nodules, particularly in the coarser Namba Formation sands. These processes were the result of widespread groundwater movements. Formation of duricrusts and related phenomena had a locus in river valleys cut into the Namba Formation, prior to deposition of the Millyera Formation.

No evidence for a major period of Oligocene to early Miocene "ferralitization" suggested by Wopfner (1974) was found in the Lake Frome area, though there is abundant evidence for late Miocene to Pliocene ferruginization and orthoquartzite silcrete Formation. This does not necessarily negate Wopfner's climatic evidence, since two periods of ferruginization are probable (Firman 1967b, 1971[8]; Jessup & Norris 1971). The older Tertiary ferruginization would presumably not be manifested in the Lake Frome area, where chemical and detrital deposition were proceeding.

The coarse detritus in the Willawortina Formation has clasts derived from Cambrian and Precambrian rocks in the Flinders Ranges. When considered in combination with poor sorting and abundant feldspar content, vigorous uplift of the Ranges is indicated. This was accompanied by movement on the Poontana Fault. A similar conclusion has been drawn by Binks (1972) from evidence on the western side of the Ranges. Ironstone and silcrete pebbles from pre-Willawortina Formation (?pre-Namba Formation) duricrust are present. However, laterite clasts are not as abundant in the overlying Willawortina Formation as one would expect in a sequence supposedly derived from erosion of a laterized land mass. Presumably this is because the Flinders Ranges were virtually non-existent at the time of deposition of the Namba Formation, presenting only a small area for laterization. Alternatively, in keeping with the suggested warm-temperate to sub-tropical climate, ferruginization may not have developed an extensive laterite crust.

Deposition in an alluvial fan environment is suggested for the Willawortina Formation by the presence of extremely poor sorting (Fig. 13), numerous channels (Fig. 12) with medium scale cross-bedding, and laminated calcareous silts (Fig. 12) with red-mottling and carbonate concretions typical of flood plain deposits. Fining upwards sequences are typified in section 11, suggesting bar deposition. The deposits coarsen very rapidly close to the Flinders Ranges. The extremely poor sorting, coarse grain-size and matrix-supported texture in some beds may be the product of mud-flows. The red mottling ('marmorization') and carbonate soils are similar to those described by Freytet (1971) in association with alluvial deposits, and typically form in the inactive parts of fans (Blissenbach 1954, p. 185; Denny 1967, p. 105). These features resemble modern fan deposits.

In sections 1 and 10 there is a tendency for overall coarsening upwards, suggesting increasingly rapid uplift of the Flinders Ranges. The uplift deluged the former lakes and swamps of the Namba Formation with detritus, reducing their extent. Thin dolomite lenses in the sequence (section 11, and Balcanoona Creek) represent lacustrine or playa lake phases similar to those of the Namba Formation. Petrological investigation shows these contain a much higher proportion of sand (much of it unstable mineral grains) than the Namba Formation carbonates.

During deposition of the Willawortina Formation, oxidizing conditions became prevalent, through accumulation of the sedimentary column above the water table. This contrasts with the sub-water table reducing environment of deposition of the Namba Formation. Abundant potash feldspar and plagioclase can be attributed to rapid deposition and possibly semi-arid climate. Presumably uplift of the

Flinders Ranges would have had a strong effect on local climate, but this cannot be assessed at present.

Following deposition of the Willawortina Formation, ferricrete and calcrete formation occurred, particularly in marginal areas.

The absence of surficial cementation of coarse sediment in the type section of the Willawortina Formation and nearby outcrop, contrasts with the ubiquitous cementation in southern areas (sections 1, 11, Fig. 3). An explanation in terms of a carbonate rich source area for groundwater or sediment, or abundance of limestone clasts in southern areas, does not explain the widespread distribution of surficial carbonate cementation in rocks of various ages throughout the Flinders Ranges. Indeed, many fans in semi-arid areas throughout the world are similarly cemented. Enough calcium is produced by weathering, or deposited from wind-born dust, to provide sufficient carbonate material for cementation anywhere. Therefore in the case of the Willawortina Formation adjacent to Mount Painter, absence of carbonate is a local phenomenon, the explanation of which is unknown.

Pt. II—Younger Cainozoic Rock Units

Type and reference sections are shown in Fig. 15, and described in detail in Appendix 2. Table 3 summarizes the lithological and other properties of the rock units dealt with in the text.

LITHOLOGY

MILLYERA FORMATION (Derivation: Lake Millyera[x], near the mouth of Billeroo Creek. Millyera is local aboriginal word for water. Map reference: *Siccus* map sheet, FROME).

The name is proposed for a sequence of interbedded greenish ostracode-bearing clays, thin limestone of charophyte algal remains, and fine sand. The sediments occur in Lake Frome or in small lakes close to its margin. The name is also applied to a coarse cross-bedded or conglomeratic sand, regarded as a fluviatile equivalent of the clays, where these contain interbedded charophyte limestones.

The type section at Lake Millyera (Fig. 15, section 4) is located 69.2 km on 320°T, northwest of Low Stony Hill (map reference *Telechie)* on the *Siccus* map sheet (Air Photo ref.: Dept. Lands Svy. 361, *Siccus* Run 1, Photo 4460).

The section consists of 4.3 m of laminated green ostracode bearing clay with a thin bed (40 cm) of laminated charophyte limestone near the top, overlain by alternating clay and fine sand. An abbreviated description is given in Table 3.

The type section was not located at the thicker section 5, where there is intertonguing with red beds. This avoids confusion which might arise should the red beds, which have affinities with certain fluviatile equivalents (e.g. the Eurinilla Formation—see later), be formalized as a distinct unit.

The contact with the Namba Formation was not exposed, but can be observed in the supplementary section located about 2 km east (Fig. 15, section 5, 68.7 km on 327.5°T northwest of Low Stony Hill—air photo reference S. Aust. Dept. of Lands Svy. 361, *Siccus* Run 1, Photo 4461).

In section 5, the Millyera Formation is 8.5 m thick, cropping out below a thick exposure of Eurinilla Formation. Here thin charophyte limestone in the Millyera Formation grades laterally into gypsum, often ripple marked (Fig. 16), intercalated in an essentially sandy sequence. Sometimes botryoidal structures are present on the surface of the gypsum layer, similar to those found on the floor of Lake Frome. Scattered very coarse polished sand grains are present on top of the gypsum, where it is in contact with the overlying red sand lens.

The red sand lens consists of a thin bed of bright red-brown coarse silt with basal granule layers impregnated with secondary gypsum, closely resembling the Eurinilla Formation in lithology. It grades by alternation to greenish very fine sand with coarse sand, silt and clay laminae (yellowish grey). The greenish sand bed is fossiliferous, with numerous charophyte oogonia and stem moulds, fish verebrate and spines, and 'Coxiella'.

The contact with the Namba Formation was exposed by trenching. Orange and yellow sands of the Millyera Formation contain reworked and oxidized tough grey sandy clay clasts from the underlying Namba Formation. The Namba Formation is more indurated and darker coloured.

The top of the sequence is marked by a strongly developed soil, also observed elsewhere affecting the Namba Formation. The soil has a crumbly texture, with peds of irregular shape about 0.5–2 cm across. A well developed black mangans is present, and reddish-to yellowish-brown iron oxide patches are developed in the clay. A similar horizon is

TABLE 3 SUMMARY OF ROCK UNIT PROPERTIES
YOUNGER UNITS

ROCK UNIT	SECTION (Fig. 15)	LITHOLOGY	SEDIMENTARY STRUCTURES	CRITERIA FOR CORRELATION	FOSSILS	AGE	GEOMETRY	GEOMORPHIC EXPRESSION	ASSOCIATED SOILS
COONARBINE FORMATION	7 (5,2,9)	Sand to silty or clayey sand, poorly to moderately sorted, usually fine grained, with subangular to sub rounded grains. 2.5-10YR3-8/4-6	Weak horizontal lamination, lenses, large scale cross-stratification (rarely well-defined).	Weakly developed bedding, moderate sorting, light brown colour, absence of gypcrete and large carbonate nodules. Locally abundant land snails. Typical soil horizon at top.	Snail shells, emu shell, aboriginal artifacts. Charales oogonia. (rare) Rare vertebrates. Burrows	EARLY PLEISTOCENE—RECENT? (From relationship to EURINILLA FORMATION)	Thin blanket 0 — 2m	Flat low-lying plains, dominates landscape of plains and self dunes. Crops out in creeks as vertical faces with columnar jointing.	Weakly developed carbonate cylindroids, weathering as hard granules. Discontinuous. Rectangular blocky structure. Forming columns of sediment.
EURINILLA FORMATION	7 (5,3,9)	Clay-sand to sand, with interbeds of silt and clay in upper part, lower part sand often with pebbles. Very poorly sorted, grains may be moderately rounded but rough and pitted, or rounded and frosted. Upper part 2.5-5YR4-9/4 7. Sandy lower part 7.10YR5-7.5/2-6. Clays 5Y7/1-2. Basal conglomerates and coarse sand with quartz pebbles and locally derived carbonate and ferruginous sandstone clasts. Coarse gypsum sands.	None or crude horizontal stratification well developed horizontal lamination (2-10cm). Sometimes developed into large scale low angle sets. Basal sands trough or planar cross bedded on medium scale. Rarely lower part horizontal wavy laminae with load casts. Low angle lunette-type cross-bedding in gypsum sand.	Poor sorting, fine upper part, coarse lower part. Upper part, lacks bedding or more rarely has well-defined sub-horizontal cross-stratification, lower part cross-bedded. Upper part reddish-brown, lower yellowish brown. Typical soil horizons, ground water calcrete and gypcrete (in basal part). Gypsum sand.	Insect burrows and nests. Vertebrates basal channels including *Diprotodon* sp. *Procoptodon goliah* *Macropus* sp. Basal layer of gastropods and lamellibranchs "Coxiella" near edge of Lake Frome. Numerous Charales oogonia, especially in coarse sand.	LATE PLEISTOCENE vertebrate fauna C_{14} dating	Thin tabular widespread sand sheet, fills hollows. 0 — 20m	Flat low-lying plains, cropping out as low slopes around depression and watercourses. Lower part often cemented by gypcrete or calcrete, producing bench or massive cap to cliff. Frequently basal channels approximate present clay drainage. Islands and mounds along S.E. shore Lake Frome gypsum lunettes.	Several well developed horizons of carbonate and gypsum cylindroids may be presented at top, soft large nodules in some areas. Frequently weather out as granules or sheets on surface. Lower sand weakly to strongly cemented with crystalline white calcite. Also with massive or layered gypsum rosettes. Mottled in shades of red-brown and white. Basal conglomerate solidly cemented with white hard to soft carbonate and gypsum of groundwater type.
MILLYERA FORMATION	4 (5,6)	Pale green laminated clay, conchoidal fracture with thin Charales limestone (5Y9/1) laminae at top, interbedded with fine well-sorted sand (2Y7/4, 5Y7/2). Limestone may grade to thin rippled-marked gypsum beds. Sand grains angular to well rounded. Reddish to white fine sand with basal pebble beds and interbedded hard thin Charales limestone beds. Algal limestone of mound springs. Clay: 10YR5/2, 5Y5/6, 5Y8-9/1-4. Fine sand: white to 2-5Y7/2-4. Channel Sand 5-10Y6-8/2.5-10YR5-8/4-7. Medium to fine greenish clayey sands.	Fine horizontal lamination in clays and limestone, assymetric small scale ripples and botryoidal blister on gypsum, oriented Charales tubules. Trough cross-bedded channel sands. Small scale cross lamination wavy bedding.	Charales tubule limestone, greenish ostracod-bearing clay, fine sand with Charales oogonia.	Charales stem moulds and oogonia. Spiral gastropods "Coxiella" sp., burrows (spiral, along bedding planes), silicified wood (pebbles, and tree trunks Coniferales) Ostracodes. Bivalves, fish vertebrae.	MIOCENE-EARLY PLEISTOCENE (From position relative to other units).	Shallow basin discontinuous linear deposits. 0.2 — 10m	In bed of Lake Frome and cropping out around edge; occupying old deeply eroded stream channels, now represented by linear lakes associated with Billeroo-Eurinilla Creek System. Mound spring limestone.	Massive white groundwater calcrete in sands, bright orange stain in basal coarse sands. Red-orange-brown mottling.

74—959 Del. B.T. R. A. Callen S. A. Dept. of Mines developed on the Millyera Formation in Section 7 of Fig. 15.

The distinction between the lacustrine facies of the Millyera Formation and the superficially similar Namba Formation can be demonstrated from Lake Millyera and Lake Tarkarooloo. In Lake Millyera, the north shore is formed by cliffs of Namba Formation clay and dolomite showing no facies changes throughout the length of the continuous outcrop. The south shore has sporadic outcrops of Millyera Formation, also unchanged along strike, traced to the junction of Billeroo Creek and Lake Tarkarooloo. These relationships suggest a disconformity between the two units. The Millyera Formation also occurs on the north shore of Lake Millyera at its eastern end, but a covered interval prevents direct establishment of a relationship with the nearby Namba Formation. The contact between the units can be observed by trenching the base of the supplementary section 5, where the erosional contact and weathered top of the Namba Formation support a disconformity.

Similar laminated ostracode-bearing clay and gypsum laminae are found beneath the base of the gypsum dunes constituting the islands of Lake Frome. These grade down to ostracode and charophyte-bearing indurated clays, without sedimentary structures, beneath the lake bed. Fine sand interbeds are present. These beds are equated with the Millyera Formation, but most sediment flooring Lake Frome, though of similar lithology, is younger and less consolidated.

Along the eastern edge of Lake Frome is a series of eroded mound springs, exhumed by deflation of the modern lake floor. These are built of saucer-shaped carbonate layers, partly algal in origin, which intertongue with the clays. These spring deposits are partly equated with the Millyera Formation.

In Lake Tarkarooloo, reddish-brown silt and conglomerate is inter-bedded with the charophyte limestone. Proceeding south along this linear lake, the coarse facies eventually dominates, the limestones being absent. The Millyera Formation is no longer identifiable, having graded into an entirely fluviatile facies of conglomerate 2–3 m thick, cemented with massive white secondary carbonate (henceforth referred to as the 'unnamed conglomerate' equivalent to the Millyera Formation). Section 6 (Figs 15, 17) shows an intermediate stage in this transition. Numerous well developed channels exhibiting π cross stratification (Allen 1963) are present, exhumed on the lake floor. They often contain clasts of fossil wood, Namba Formation dolomite, ferruginized Namba Formation sand, and milky quartz at the base, demonstrating a disconformable relationship with the Namba Formation. There is little facies change along the length of Lake Tarkarooloo in the Namba Formation, whereas the Millyera Formation varies considerably, though retaining its identity as a unit.

Two charophyte limestone horizons were developed in the southern part of Lake Tarkarooloo, instead of one as at Lake Millyera. Since they must have once represented a horizontal lake shoreline, and are equivalent to the horizon at Lake Millyera, structural deformation (?faulting) is required to account for their relatively higher position in the landscape. Barometric levelling, tied in with South Australian Department of Lands bench marks, established the height difference (see Sections 5 and 6, Fig. 15). Comparison of the heights of equivalent Namba Formation carbonates, between Lake Millyera and the Namba Formation reference section in Lake Tarkarooloo (Fig. 14) also supports downfaulting of the Lake Millyera region.

The "unnamed conglomerate" channel equivalent of the Millyera Formation can be traced throughout the area southeast of Lake Frome, where it is invariably overlain by the Eurinilla Formation. The disconformity is difficult to detect away from low-lying areas such as Lake Tarkarooloo, where well-developed greenish carbonate nodules and cylindroids of a soil calcrete mark the contact, and massive white groundwater carbonate cements the conglomerates in the Millyera and Eurinilla Formations. Elsewhere the conglomerate has a weak earthy carbonate cement and interbedded secondary gypsum layers, interpreted as groundwater phenomena rather than soils. The contact with Eurinilla Formation appears gradational (e.g. units 1 and 2 of the Eurinilla Formation in section 8, Fig. 15), and it is not possible to establish a disconformity. An additional problem in the Millyera Formation is the repetition of red sand facies resembling those of the Eurinilla Formation. This suggests it may be possible to have two red facies superimposed. The contact between unit 2 and 3 in section 8 may represent such a boundary (i.e. the lower part of this section may correlate with the Millyera Formation).

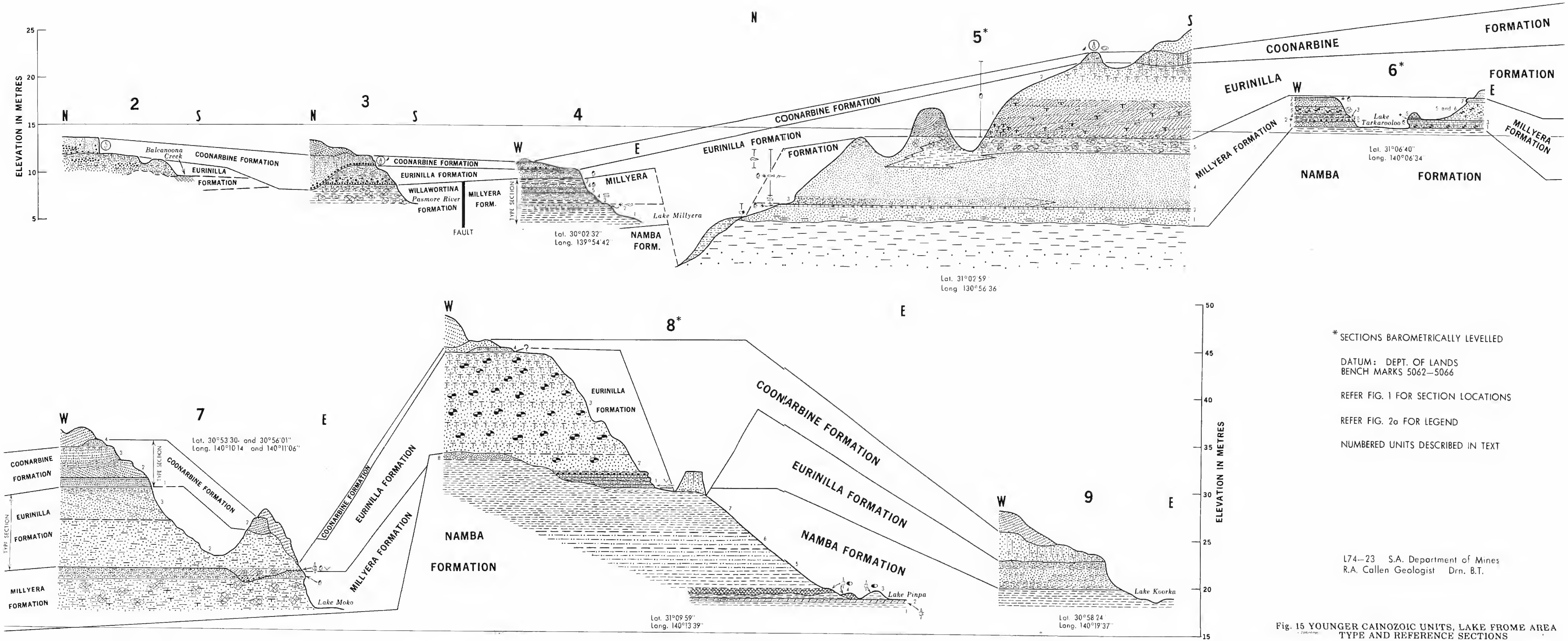


Fig. 15 YOUNGER CAINOZOIC UNITS, LAKE FROME AREA
TYPE AND REFERENCE SECTIONS

1100–6.76 G6808 O

Current directions were recorded from a variety of cross-bedding types in widely scattered localities in the basal channel facies (both sands and conglomerates), though with a bias towards the Lake Tarkarooloo area, but are sufficient (45 measurements) to record a north to northeasterly transport direction. Conglomerates such as those of section 8, where no disconformity between the Eurinilla and Millyera Formation was established, were not included in this analysis.

EURINILLA FORMATION (Derivation, Eurinilla Creek, *Eurinilla* map sheet, CURNAMONA).

The type section (section 7, Fig. 15) is located at Lake Moko* on the junction between Billeroo and Eurinilla Creeks (Air Photo Ref. —S. Aust. Dept. Lands Svy. 395, *Coonarbine*, Run 3, Photo No. 9637). The locality is 45.8 km on 332°T from Billeroo Waterhole (CURNAMONA—Billeroo Creek), and the outcrop (Fig. 20) occurs in an amphitheatre, formed by gullies draining into the north end of the lake. The upper fine grained facies is well developed. The complete section is described in Appendix 2. Section 7 was constructed from two outcrops 200 m apart, correlated by following the beds along strike.

This sequence consists of three units, separated by a weak carbonate soil horizon. The lower unit, exposed in the southern outcrop, consists of 1.8 metres of white well sorted medium grained channel sand. It is cross-bedded, and contains some vertebrate remains, clasts of underlying units, and charophyte oogonia. The sands have features similar to channel sands elsewhere at or below the base of the Eurinilla Formation. An interesting feature is the presence of biotite, suggesting nearby crystalline basement outcrop at the time of deposition. Unit 1 is overlain by the much more widespread and typical red silty and sandy facies of units 2 and 3, respectively 5.3 and 5.5 m thick. These units are separated by a weak carbonate soil horizon. The lower is paler than the upper, and shows no evidence of bedding. It grades to clay-silt at the base. The upper unit has diffuse large scale cross-bedding, is sandy, and orange-coloured throughout. It is capped by a well-developed fossil soil horizon with nodules and cylindroids of carbonate and some gypsum.

The sequence is overlain above the fossil soil by a horizontally laminated sand, similar to that at the top of Unit 2, but with more pronounced bimodality. Since the soil represents a disconformity, these sands are excluded from the definition, and placed in the Coonarbine Formation.

Another section 8 m thick (section 5, Fig. 15) is situated on a steep bluff facing north, on the southern side of Lake Millyera, close to the Millyera Formation type section 4. A detailed description is in Appendix 2. The sands are paler than those of the type, and contain low angle cross-bedding at the base. The overall two-fold division (of units 2 and 3) in the type section is retained. A diffuse thin bedding dips toward Lake Millyera. Considered with the geometry of the outcrop, the sequence is interpreted as a small delta.

The upper part of this sequence has tubules and cylindroids of soft white carbonate and gypsum, several centimetres diameter, forming several inter-related horizons representing a fossil soil complex. The tubules weather out as hard cylinders. The lower part of the sequence is partly cemented with sheets of soft white carbonate, and with pink carbonate nodules. The base is solidly cemented with gypsum, partly derived from the dissolution of gypsum lunettes (represented by low angle cross-bedding).

A third reference section of 3 m thick is located at Lake Koorka* (Fig. 23), a small claypan on Eurinilla Creek, close to the boundary between FROME and CURNAMONA on *Eurinilla* map sheet. The western edge of the pan is formed by a cliff 6 m high, where section 9 (Fig. 15) was measured (Appendix 2). Here, the Eurinilla Formation is represented by mottled very pale orange and strong brown clayey silt without stratification, capped by a massive gypsum horizon with 0.5 cm rosettes of gypsum crystals developed in red-brown silt and gypsum flour. It disconformably overlies the Namba Formation.

Burrowed horizons and gypsified roots are locally common in the Eurinilla Formation, though not represented in the sections described here.

The carbonate zones at the top of the Eurinilla Formation in sections 5 and 7 are regarded as a single widespread paleosol. They differ from the soil developed on the overlying Coonarbine Formation by having larger patches of carbonate segregation, often in several horizons, frequently weathering out as solid sheets or lumps. In the Arboola Claypan* large soft calcareous "biscuits" are developed, in which the original lamination of the cemented sediment is visible. This paleosol has been identified along Balcanoona and Poontana Creeks, on the west side of Lake Frome (Figs 1, 15, section 2) where it is developed in coarser grained sediments.

The Eurinilla Formation is often underlain by a coarse cross-bedded sand or conglomerate, ?'unnamed conglomerate' usually partly cemented with hard white lime. The beds are light pinkish brown, from iron-staining on sand grains. A typical sequence including this facies occurs at Lake Pinpa reference section (section 8, Fig. 15, and Appendix 2). The basal conglomerate often contains clasts of Namba Formation dolomite or Willawortina Formation carbonate nodules. At Lake Tarkarooloo the islands on the lake floor (especially near section 6, Fig. 15, where massive carbonate cemented pink sands and conglomerates are interbedded with the charophyte limestone), demonstrate the gradation to the Millyera Formation.

The disconformity between the Millyera and Eurinilla Formations is exemplified in sections 5 and 7, but is not at all obvious in section 8, or elsewhere away from the vicinity of Lake Frome. The relationship can, however, be observed along the Pasmore River, particularly where the main Yunta to Flinders Ranges road crosses. Here, two terraces of secondary carbonate-cemented conglomerate occur, interbedded with yellowish sands containing greenish white carbonate nodules at the top. The nodules are interpreted as a paleosol, and occur in similar yellowish sands of the Millyera Formation in Lake Tarkarooloo. Therefore the unnamed conglomerate and associated sands are regarded as Millyera Formation equivalents.

The red brown silty Eurinilla Formation with its characteristic soil developed at the top, infills a valley cut into the 'unnamed' conglomerate, and associated sediments. The whole is cut into Willawortina Formation sandy clays. Light brown sands of the Coonarbine Formation disconformably overlie all units at various levels in the landscape.

The relationships between the Eurinilla and Willawortina Formations is also exhibited in section 3 at the mouth of the Pasmore River (Fig. 15 and Appendix 2) where reddish-brown pebbly silt with a basal conglomerate (Eurinilla Formation) rests with sharp erosional disconformity on pale green and red-brown mottled clay (Willawortina Formation).

On a regional scale the disconformity surface between the Eurinilla Formation and Coonarbine Formation is flat, but locally, river valleys are developed.

Within Lake Frome are several islands consisting of up to 10 m thick of coarse well rounded gypsum sand with minor quartz, and interbeds of clay pellets. These exhibit the low angle cross-bedding, lithology and geometry of lunettes described by Bowler elsewhere in Australia (pers. comm. 1974, J. M. Bowler). The sands rest disconformably on the Millyera Formation indurated clays, and are tentatively correlated with the Eurinilla Formation. Similar lunettes flank the eastern shore of Lake Frome.

COONARBINE FORMATION (Derivation Lake Coonarbine, *Coonarbine* map sheet, FROME).

The type section is located at Lake Moko section 7, Fig. 14 and Appendix 2), mentioned earlier. The sequence (Fig. 20), resting disconformably on the Eurinilla Formation, consists of three parts—a basal 1.0 m of a red brown indistinctly laminated sand, overlain by 3.3 m of light brown dune sand (two large scale cross-bed sets are represented) with a carbonate soil horizon at the top. This is overlain by 0.6 m of light brown sand with carbonate patches and rhizondules. The laminated sand at the base of this sequence may be a distinct unit in its own right, since it has features different from the remainder of the Coonarbine Formation. Its disconformable relation with the Eurinilla Formation has been established.

The carbonate soil horizons are much weaker than those of the Eurinilla Formation in the same section and at section 5 (Fig. 15). The upper more prominent horizon is correlated with that at the top of section five. The Coonarbine Formation in this section exhibits the typical blocky joint pattern, producing 5 x 10 cm columns of sediment (large ped structures). Land-snail shells occur here, and at other widely separated localities, being characteristic of the unit. The uppermost layer is associated with aboriginal artifacts and emu shell fragments. The Formation can be traced west to the Pasmore River (e.g. section 3) where it overlies the Eurinilla Formation.

An important supplementary section (section 2, Figs 15, 21 and Appendix 2) representing a coarser facies of the Coonarbine Formation of western Lake Frome, is found in Balcanoona Creek, near the natural gas pipeline (Air Photo Ref.: S. Aust. Dept. Lands Svy. 394, *Arkaroola* Run 3, Photo No. 0078). At this site the old land surface on top of the Eurinilla Formation is exposed. The overlying beds of the Coonarbine Formation consist of 1.70 metres of dark brown, sandy silt, with a basal pebble bed, moderately poorly sorted. No bedding planes are visible, and columnar ped structure is well-developed.

Immediately downstream the surface of the Coonarbine Formation is scattered with aboriginal artifacts, the colour is redder, and land snail shells are present. Upstream, near Mulga Bore on "Balcanoona", the basal pebble bed has 0.5–1 m thick lenses, cutting into the Eurinilla Formation. Carbonate nodules from the soils developed in the Eurinilla Formation are eroded and incorporated into the basal Coonarbine Formation.

East of Lake Frome the fluviatile facies of the Coonarbine Formation gives way to aeolian seif dunes, forming the partly indurated cores of the modern dunes of the southern Strzelecki Desert. Exposures occur along the flanks of the modern dunes. The gypsum lunettes of the islands have a deposition break within them, the significance of which is uncertain: it is likely that the part above the break corresponds to the Coonarbine Formation.

RELATIONSHIPS BETWEEN FORMATIONS

The Millyera Formation rests disconformably on the Namba Formation in Lakes Millyera and Tarkarooloo, but its relationship to the Willawortina Formation is less clear. The correlation of conglomerates and sands at the Pasmore River Section with similar facies at Lake Tarkarooloo has been mentioned, and suggests the Millyera Formation conglomerate equivalent is also disconformable on the Willawortina Formation. The relationship is similar to that at the "Wertaloona" section. Further support is derived from the presence of bright orange to red-brown silt and sand, similar to that in the Millyera Formation of section 5, intertonguing with the conglomerate around the mouth of Balcanoona Creek.

At the "Wertaloona" section (section 1, Fig. 3) the dipping sequence of Willawortina Formation is overlain with angular unconformity by a small patch of horizontal conglomerate and yellow sand, regarded as Millyera Formation equivalent. The conglomerate contains pebbles of ferruginized material, derived from what was probably a widespread surface, now exhibited as small remnants in the same valley. This ferruginization is correlated with that beneath the Millyera Formation at Lake Tarkarooloo, and elsewhere. Deformation of the Tertiary sequence occurred before deposition of the Millyera Formation and development of the ferruginous horizon.

The disconformity between the Eurinilla Formation and Willawortina Formation can be seen in cliffs along the Pasmore River. The clearly disconformable relationship between the Millyera Formation and Eurinilla Formation is seen in section 5 (Fig. 15). The disconformity is less obvious for its equivalent, the "unnamed conglomerate" of Lakes Tarkarooloo, Pinpa (?units 1 and 2 of section 8, Fig. 15), and elsewhere.

Relationship between Eurinilla and Coonarbine Formations can be easily observed (for example in sections 2, 3, 7 and 9, Fig. 15). The Coonarbine Formation can be frequently seen cutting into the Eurinilla Formation, and the two units usually have contrasting lithology. The soil carbonate at the top of the Eurinilla Formation may be completely eroded and reworked into the younger unit.

Rock relationships are summarized in Fig. 24.

AGE

The Millyera Formation has equivalents at the southern edge of Lake Callabonna, and northern end of Lake Frome. It closely resembles laminated green clays and sands bearing *Diprotodon* found in the main part of Lake Callabonna. The temporal range of *Diprotodon* is Pliocene to late Pleistocene. A wood radiocarbon age of >40 000 years B.P. (Daily 1960) from these beds has lately been confirmed by another wood radiocarbon date of >39 900 years B.P. (Tedford 1973). At the mouth of Poontana Creek, on the Lake Frome —Lake Callabonna confluence, dates from shells in sands equated with the Millyera Formation give ages of >33 400 years B.P. and 35 200 ±1 200 years B.P. (GaK–4949, GaK–4948). This shell material has been affected by younger pedogenesis, converting them to calcite (assuming the shells were originally all aragonite as are most non-marine molluscs). Therefore the dates are minimal, and the Millyera Formation has an age in excess of 34 200 years B.P., probably >40 000 years B.P. Similar shell beds in a similar stratigraphic sequence were recorded at Lake Eyre, and gave a date of 39 200 ± 1 300 years B.P. (Johns & Ludbrook 1963).

The Eurinilla Formation contains late Pleistocene vertebrate fossils, somewhat different in generic composition to those at Lake Callabonna. The fauna occurs in channels at the base of the unit, along Billeroo Creek east of Lake Pinpa.

The overlying Coonarbine Formation is probably late Pleistocene or early Recent.

REGIONAL CORRELATION

Equivalents of Millyera Formation are little known at present, though the sequence described immediately above the Etadunna Formation in the Madigan Gulf region of Lake Eyre North is apparently very similar (King 1956, Ludbrook 1956, Johns & Ludbrook 1963). The lithological similarity between the fossiliferous greenish sands containing *Coxiella gilesi* in Madigan's Gulf, and those in the Millyera Formation of section 5 (Fig. 15) is marked. All these beds are close to or beyond the limits of radiocarbon dating, but the closely comparable micro-fauna (including *Elphidium* spp., *Ammonia beccarii*, *Nonion* sp: pers. comm. J. M. Lindsay 1974), charophytes and molluscs tend to support correlation. The Lake Eyre sequence rests on the Etadunna Formation, and is overlain by rocks resembling the Tirari Formation.

The Eurinilla Formation closely resembles the Tirari Formation of the Lake Eyre Basin, in lithology, stratigraphic position and topographic expression. Vertebrate faunas in basal Eurinilla Formation channels indicate equivalence with the youngest Katapiri Sand (Stirton *et al.* 1961) of the same basin.

Other possible equivalents are indicated in Table 4. The Pooraka Formation (Firman 1966a) supposedly rests on Telford Gravel (Firman 1963) on the west side of the Flinders Ranges, and is overlain by the Lake Torrens Formation (Williams & Polach 1971). The unnamed conglomerate equivalent of the Millyera Formation lithologically resembles the Telford Gravel at Telford open cut, Leigh Creek. The Eurinilla Formation, lithologically resembling the Lake Torrens Formation, overlies the Millyera Formation, and is in turn overlain by the Coonarbine Formation. The latter is similar to the Thomson Creek Formation of Williams & Polach. There also are similarities in the calcareous soil horizons of each, in the same geomorphic situation.

The Pooraka Formation, Telford Gravel and "unnamed conglomerate" of Lake Frome area are probably equivalents. It has been suggested by Firman (1971)[8] that the Telford Gravel is equivalent to the whole of the Tirari Formation (Eurinilla Formation correlative), but this cannot be the case in the Lake Frome area. The youngest *probable* equivalents here are the conglomerate at the base of the Eurinilla Formation, and the most *likely* correlative the "unnamed conglomerate" equivalent of the Millyera Formation.

The unit mapped as Pooraka Formation on COPLEY (Coats 1973) is Coonarbine Formation. During mapping COPLEY, Callen & Williams (in Coats 1973) recognized a unit of reddish brown sand and cobbles which covered most of the surface of the high level plains flanking the eastern Flinders Ranges. The unit was later named the Arrowie Formation by Coats (1973): subsequently mapping for FROME has shown it is probably partly equivalent to the Coonarbine Formation. The two units both contain land snail shells, and appear to grade laterally into one another at the break in slope at the base of low hills south of "Wertaloona." However, Coats seems to include some younger and older gravels in his definition, with ?disconformable relationships.

ENVIRONMENT

The Millyera Formation constitutes three facies groups: the most typical and widespread are the laminated ostracode clay and charophyte limestones (Fig. 18), with associated charophyte oogonia-bearing fine sand. Fine lamination, ostracodes, and distribution of sediment, indicate they are undoubtedly of lacustrine origin. The fine sands are well rounded and smooth and may therefore be aeolian, having been blown into the lake, or carried by floods. Drying of the lake is indicated by the charophyte limestone and equivalent gypsum lamellae (Figs 16, 18; cf. Reeves 1968, p. 57, 58). Similar modern calcareous algal deposits (Fig. 19), grading to rippled gypsum crusts, are present in Lake Kutunu[9]. Waves acting on the very shallow water bodies break up the filaments and orient them in crescent like ripples, sometimes resembling the oriented structures in their fossil equivalents. The gypsum laminae may have botryoidal surfaces that are reminiscent of similar forms

TABLE 4 CORRELATION CHART – YOUNGER UNITS

TIME UNIT	LAKE FROME AREA: CALLEN & TEDFORD, This paper		SUGGESTED EQUIVALENT – ADJACENT MAP SHEETS AND OTHER BASINS: FIRMAN, N. Western Flinders Ranges, Lake Eyre Basin	COATS et al., COPLEY 1:250 000 map sheet	WILLIAMS and POLACH, 1971, Western Flinders Ranges	STIRTON et al., 1961, Lake Eyre	TEDFORD (1973, pers. com.) Lake Callabonna
RECENT	Modern dunes Lake deposits Stream bedload	Mound spring deposits	SIMPSON SAND CALLABONNA CLAY	?— —?	THOMSON CREEK F. (upper part)		
PLEISTOCENE-RECENT	Fossil calcareous soil horizon	Mound spring deposits	LOVEDAY SOIL	ARROWIE FORMATION	NACOONA PALEOSOL		
	COONARBINE FORMATION includes gypsum lunettes	Mound spring deposits	POORAKA FORMATION	?— —? POORAKA FORMATION	THOMSON CREEK FORMATION (lower part)		COONARBINE FORMATION Equivalent (Fossil bird-bearing unit)
PLEISTOCENE	Fossil calcareous soil horizon	Mound spring deposits	LOVEDAY SOIL		MOTPENA PALEOSOL		
	GYPCRETE and CALCRETE of basal Eurinilla Formation (Stratigraphic significance uncertain)	Mound spring deposits	?BAKARA SOIL	GYPCRETE AND BAKARA SOIL			
	EURINILLA FORMATION ?—?—CALCRETE	Mound spring deposits	POORAKA FORMATION BAKARA SOIL	↓	LAKE TORRENS FORMATION WILKATANA PALEOSOL	TIRARI FORMATION and KATAPIRI SAND	
	UNNAMED CONGLOMERATE / MILLYERA FORMATION	Mound spring deposits	TELFORD GRAVEL	TELFORD GRAVEL			MILLYERA FORMATION Equiv. (Diprotodon bearing unit)
LATE TERTIARY TO EARLY QUATERNARY	WILLAWORTINA FORMATION	?	—?— —?—	'T–Q' Unnamed conglomerates and clays		—?— —?— MAMPUWORDU SANDS —?— —?—	

74–421 R.A.Callen S.A. Department of Mines on the surface of modern Lake Frome, produced by crystallization pressure buckling the surficial crusts.

The second facies group is the channel facies (Fig. 17), of conglomerate/sand which exhibits features of meandering streams of large size containing bed-forms of slightly crescent-shaped aqueous dunes. The streams carried pebbles from the Olary Ranges, and eroded valleys into the Namba Formation. These deposits are lateral equivalents of the "unnamed conglomerate" which is so extensive along the Siccus—Pasmore River System.

The third facies group are the greenish fossiliferous sands, which (Section 5, Fig. 15) are cross-bedded on a small to medium scale, and contain shell beds and fish vertebrate. Similar shells are also abundant in a narrow zone along Billeroo Creek between Lakes Kuturu and Tarkarooloo. These deposits are interpreted as shoreline facies of the Pleistocene Lake Frome.

These sediments, and equivalents at the northern end of Lake Frome, contain the foraminiferal assemblage mentioned earlier (p. 147). Similar species were also recorded by Ludbrook (Ker 1966, p. 94) in equivalent strata in McKenzie Bore, 7.5 km south south-east of section 5. The presence of several species of foraminifera over a wide area in the same sediments can be explained in terms of Ludrook's (1965) hypothesis of transport to salt lakes on the feet of seabirds, with subsequent survival for a period. The species present are mostly Rotaliina with a wide salinity tolerance, and diversity is low. Such a situation is typical of inland saline lakes (Resig 1974), where foraminifera have been introduced by some dispersal mechanism from coastal areas. Species such as *Ammonia beccarii* are common in these environments. Although the assemblages found at Lake Eyre and Lake Frome are considerably different in content from those listed in Table 4 of Resig's paper (e.g. *Nonion* spp. are not recorded, though common at Lakes Frome and Eyre) this does not detract from the dispersal hypothesis because each locality cited in her paper has high endemism. The Coorong area contains a similar assemblage (pers. comm. J. M. Lindsay 1975), though its low diversity is probably the result of high salinity, even though it has a connection with the sea.

Another explanation is that there was a distant connection to the sea, implying a high sea level during the Pleistocene prior to 40 000 years B.P.

The detrital component of the lacustrine Millyera Formation sediments were brought to the ancestral Lake Frome by large braided streams with a pebble bed load ("unnamed conglomerate") approximately following the channels of present day watercourses such as the Pasmore-Siccus River system, and the Lake Tarkarooloo-Billeroo Creek system. They were much more extensive than their modern counterparts. The clasts indicate a provenance similar to the modern streams, in the Olary

Figs 16-19. Younger Units. Structures in Millyera Formation.

Fig. 16. Millyera Formation. Laminated ripple-marked gypsum and clay (Fig. 15, section 5). Scale 30 cm.

Fig. 17. Plan view of cross-stratified channel sand in Millyera Formation channel facies, bed of Lake Tarkarooloo near Section 6, Fig. 15. Approximates Pi cross-stratification. Current direction (arrowed) is to north. Hammer handle 25 cm long. Laminae emphasized by inking.

Fig. 18. Algal tubules showing rough orientation. Same locality as Fig. 22. Scale in cm.

Fig. 19. Modern calcareous charophyte algal filaments, Lake Kuturu, showing crude orientation. Thin crust of gypsum (G) in upper central part of photograph.

Figs 20-23. Outcrop.

Fig. 20. Upper part of section 7, Fig. 15, showing dune sand facies of Coonarbine Formation (two upper benches), basal laminated sand (bench just above contact), and upper part of Eurinilla Formation with calcareous paleosol (just below contact).

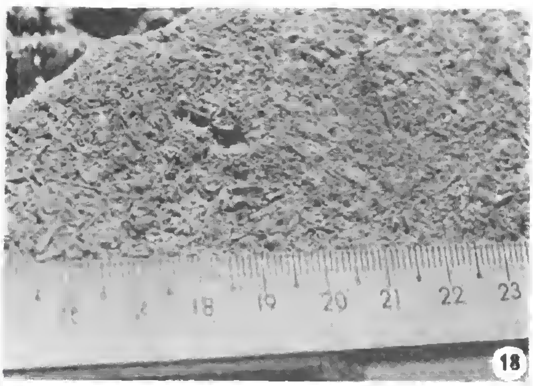
Fig. 21. Section 2, Fig. 15, Columnar-structured sand of Coonarbine Formation overlying Eurinilla Formation. Surface in foreground shows carbonate patches of paleosol, and represents the pre-Coonarbine Formation land surface slightly modified by present erosion. Scale 30 cm.

Fig. 22. Coonarbine Formation sand with columnar jointing, overlying Millyera Formation which in turn overlies Namba Formation. Millyera Formation shows upper algal limestones and lower massive sandy limestone (prominent benches) with intervening clayey sand. Lake Tarkarooloo, near Coombes Bore. Scale 30 cm.

Fig. 23. Section 9, Fig. 15 (lower part). Coonarbine Formation, disconformably overlying Eurinilla Formation which has its upper surface cemented with secondary gypsum (prominent bench). Black clay of Namba Formation at base (30 cm scale crosses contact).


16


17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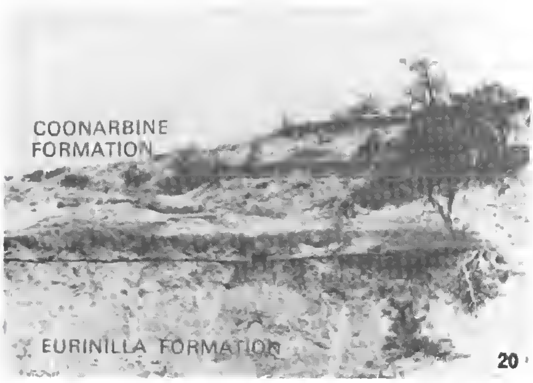
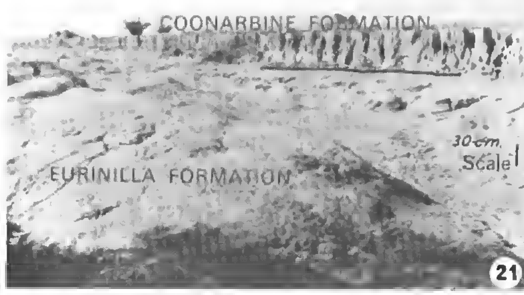
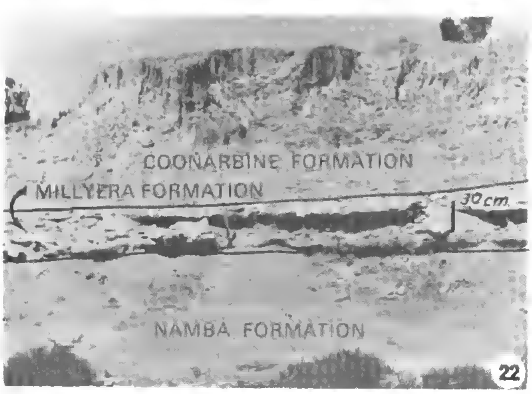
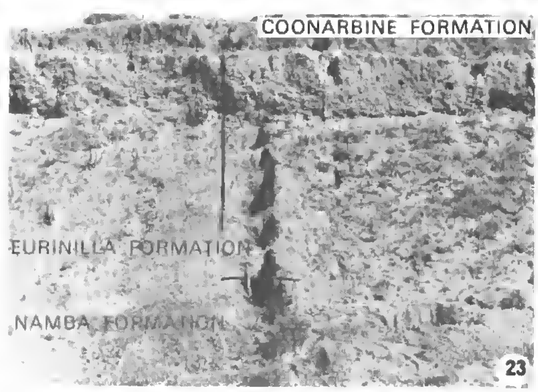

COONARBINE FORMATION
EURINILLA FORMATION
20


COONARBINE FORMATION
30 cm. Scale
EURINILLA FORMATION
21


COONARBINE FORMATION
MILLYERA FORMATION
30 cm
NAMBA FORMATION
22


COONARBINE FORMATION
EURINILLA FORMATION
NAMBA FORMATION
23

Ranges and southern Flinders Ranges. Large straight-crested aqueous dunes typified the streams with coarse sandy and pebbly bed loads, whereas crescentic dunes characterized the streams with a finer sand-bed load. The eastern shore of Lake Frome was estimated to be about 10 km further east than at present.

The Eurinilla Formation contains channel deposits, exemplified by coarse sand with parting lineation and cross-bedding, in troughs and point bar deposits along Billeroo Creek. The meandering form of these channels can sometimes be seen on aerial photographs. The pebbles have sources in the Flinders Ranges or Olary Ranges, or have been eroded from the underlying Tertiary units. Flood-plain deposits are represented by the finer facies, which is sometimes laminated. The initially fluviatile phase (basal coarse grained sands) gave way to a more complex environment with finer fluviatile deposits and large scale cross-bedded aeolian deposits, including huge gypsum lunettes along the south western shore and on the islands. Some possible loess (massive silt and very fine sands) is present. These sediments transgressed over the older lake deposits of the Millyera Formation. The ancient Lake Frome therefore decreased in size in medial Pleistocene times, being somewhat smaller than at present.

The plains of this essentially fluviatile environment were inhabited by large marsupials (*Diprotodon* sp., *Procoptodon goliah*, *Sthenurus* sp. and *Macropus* sp.) Rivers followed approximately the same coarses as the present day drainage. The distribution of lunettes indicates a dominant wind direction from the west and a strong westerly component still characterizes this region.

The overlying Coonarbine Formation includes fluviatile braided stream environments west of Lake Frome, and dominantly aeolian east of the lake. The fluviatile sediments have less defined channels than the Eurinilla Formation, pebble sheets being more common. East of Lake Frome longitudinal dunes were developed, and another minor phase of gypsum lunettes built up along the lake shore. Land snails probably lived around water holes.

Conclusions

The new rock units in the Lake Frome area record a history of intermittent deposition through Miocene to late Pleistocene-Recent times. During this interval the extensive rivers, lakes and possibly estuarine environments of the Miocene Namba Formation drained areas of low relief in a climate of high rainfall, and of higher annual temperature than the same latitude today. At times, seasonal dry periods became a part of the weather pattern. A connection with the sea was established at some stage, probably to the Murray Basin. Some conflicting climatic evidence is partly resolved by applying the continental lessivage hypothesis (Millot 1964, as modified by Wiersma 1970) in relation to the smectite—dolomite—palygorskite mineral suite. Thus warm tem-

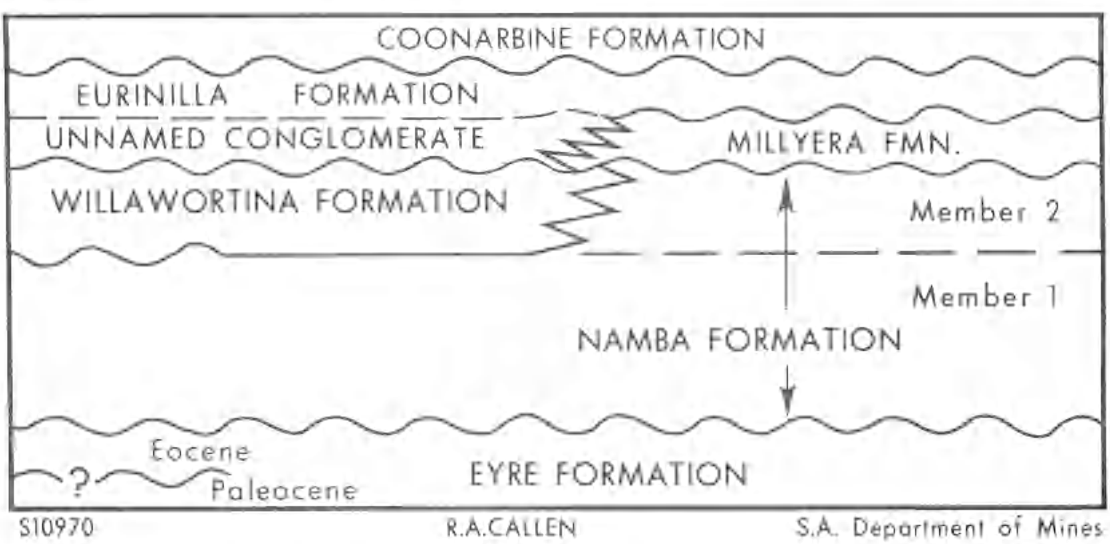


Fig. 24. Cainozoic rock stratigraphic relationships, Lake Frome.

perate to subtropical conditions prevailed, with savannah landscape, and gallery forests around the large permanent streams and lakes.

Uplift of the Flinders Ranges occurred at the earliest during late Miocene times, continued through the Pliocene intermittently into the Quaternary, and is still proceeding at present. Prior to this, at least during the Cainozoic, the Flinders Ranges were virtually non-existent. The sediments deposited during the Pliocene-early Pleistocene Epochs record the change from the earlier Miocene palaeogeography to the very different landscape approximating that of the present. Lakes and swamps during Tertiary times disappeared during the Pleistocene, as tectonism and climatic change altered the depositional regime. Drainage resembled that of the present during the late Pleistocene, indicating the basin was approaching its present configuration.

The Millyera Formation indicates active deposition on a playa lake somewhat larger than the present. The changing character of the sediments from Millyera to Coonarbine Formation suggests overall increasing aridity, probably seasonally distributed during Eurinilla Formation times, as exemplified by the formation of the gypsum lunettes. Marked climatic fluctuations were superposed on this overall climatic trend. Uplift of the ranges continued, alternating with periods of stability during which soils developed.

Rock relationships are summarized in Fig. 24.

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Appendix I

OLDER CAINOZOIC UNITS

Fig. 3, sections 1, 10, 11, 12. Fig. 14, section 13

NAMBA FORMATION TYPE SECTION

SADM Yalkalpo No. 1 Stratigraphic Bore. Fig. 3 Section 12

COONARBINE FORMATION

2.00. SAND, medium grained, strong reddish brown (2.5YR4/6). Subrounded grains. Rectangular joint pattern and carbonate cylindroids in upper part.

— Disconformity —

NAMBA FORMATION

Unit 18. 3.40 — 1.40 CLAY, slightly silty, with scattered gypsum spots. Light grey (N.4) with moderate yellowish orange (10YR5/6) patches. Sharp upper contact.

Unit 17. 4.75 — 1.35. Interbedded SAND and CLAY overlain by SILT. Sand is very fine grained, laminated and small scale cross laminated, as are the silt beds at the top of the unit. Lower beds have structure destroyed by secondary gypsification. Contacts between sand and clay beds are sharp and flat. Sand-filled shrinkage cracks extend down from the wavy irregular upper contact.

Unit 16. 12.00 — 6.45. SILTY CLAY. Poorly sorted, diffusely laminated. Two silt beds with gradational to sharp contacts near the top, lower 1 m burrowed and bioturbated with wavy irregular upper bedding plane separating it from the remainder of the sequence. Irregular shiny fracture planes (crumbly texture) and gypsum nodules developed in upper part. Light to moderate olive grey (5Y4/2–5Y5/1. 5–5Y6/1). Mottled black and yellow (5Y4/0.5) in lower silt.

0.60. No recovery.

0.20. As before. Shrinkage cracks filled with sand extend down from upper unit—wavy irregular contact. Light olive grey (5Y5/2).

Unit 15. 12.20 — 0.20. SILT. Laminated, very fine cross-laminated, burrowed in part. Very pale yellowish grey (N1 to 5Y9/1). Upper contact sharp and flat, burrowed.

Unit 14. 15.20 — 3.00 SILTY CLAY. Intraformationally brecciated. Burrowed and bioturbated in lower half, upper half with angular clay clasts and slump structures. Upper contact sharp, flat.

Unit 13. 17.30 — 1.70. CLAY SILT and CLAY. Poorly sorted. Clay beds near centre. Burrowed at top, intraformational brecciation common. Pale to light olive clay (10Y6/2 to 6/4), silt pale grey to pale yellowish grey (5Y8/1 to N7). Upper contact sharp and flat.

0.40. SAND and SILT, interbedded, weakly laminated, wavy sharp contacts between interbeds. Sand is very fine, very angular (quartz crystal faces—overgrowths on rounded grains, contacts between overgrowth and grain visible).

Unit 12. 19.59 — 1.05. No recovery.

1.24. SAND, grading up to CLAY SILT and SILT. Sand has small-scale cross lamination with heavy mineral laminae.

Unit 11. 21.52 — 0.05. CLAY, black as below. Contact with overlying bed sharp and flat.

1.13. No recovery.

0.75. SAND, grading up to CLAYEY SILT. Sand very fine, wavy lamination. Colour 5Y6/4.

Unit 10. 26.82 — 0.20. SILT and CLAY, interlaminated, flame structures on contacts. Light olive grey (Clay 5Y6/1, Silt N9). Contact with unit 11 sharp and flat.

2.30. SILT, lower bed laminated and cross-bedded, with scattered burrows.

result of bioturbation and extensive burrowing. Upper contact wavy and irregular.

0.30. CLAY, laminated, colour NO, 4Y4/2. With CHELONIA scute at 24.21 m. Upper contact sharp, with flame structures.

1.40. SAND, fine grained in lower 1/5 grading up to laminated and burrowed light grey (N5) SILT. Sand grains smooth and shiny, angular, some well rounded and frosted, many with crystal faces and re-entrants. Upper contact wavy and irregular. Grading down to . . .
1.10. SILT, laminated and small scale cross-bedded, with scattered burrows.

Unit 9. 35.52 3.20. CLAY, black (N1) mottled light olive brown (5Y5/6), with sand patches and other features as before. Contact with sand lower in unit gradational. Large sand grains in the patches are polished, rounded to well rounded, smaller grains being angular to subangular with overgrowths(?). Some of the larger grains show rounded crystal forms.
0.35. No recovery.
3.60. SAND, as below. Calcite patches and very coarse mica common. Polymodal, poorly sorted overall. Small sizes angular, coarse are rounded, some doubly terminated crystals. Interbedded light grey (N7) clay in centre of unit. Becoming well sorted and fine grained at top with mixed well rounded and angular grains. Obscure small scale cross bedding and lamination.
0.60. No recovery.
0.95. SAND. Coarse to medium grained, slightly calcareous. Large grains polished, others with crystal faces (overgrowths?) which give stepped shiny surfaces. Many grains show original elongate quartz prism shape.

Unit. 8 36.22 0.70. Alternating SAND and CLAY. Sand very fine grained with small scale trough cross-lamination. Clay olive to medium grey (5Y5/0.5).

Unit 7. 39.22 0.30. Clay as below. Sharp wavy upper contact.
1.25. No recovery.
1.45. Alternating SAND-CLAY fining upwards sequences. Several thin beds, beginning with very fine grained sand at base. Sharp flat contacts, grading to black (N2, 5YR2/1) clay with orange brown specks and sand patches in top 20 cm.

Unit 6 40.79 0.94. SANDY SILT, grading up to CLAY. Black (N2) clay as for unit 5, with fine sand patches, 1/3 of sequence. Sharp wavy upper contact.
0.58. No recovery.
0.05. SILT with slump structures.

Unit 5. 47.44 6.55 SAND, SILT and CLAY alternating in lower 1/3, grading to CLAY at top. Lithology as for unit 4. Obscurely laminated in lower part, lenticular bedding. Light olive grey (5Y6/1) with oxidised brown patches (10YR6/6). Calcareous at transition (25 cm) to dark clay. Sand distributed in vertical streaks and patches through the dark olive clay (5Y5/1). Irregular wavy upper contact.

Unit 4. 50.84 3.30. SILT, grading up to CLAY. Lower 1/3 laminated silty and clay with very-small to small scale cross bedding at base, some burrows. Pale yellowish grey (5Y9/1) and pale olive (10Y6/2). Grades rapidly into sandy clay with vertically oriented structure and lime streaks, yellowish grey to pale olive (5Y7/2 to 9Y8/2). This grades to tough black (N1) clay with orange brown dendritic mottling and patches of fine sand. A thin brown band of iron oxides is present. Upper contact wavy, irregular.

Unit. 3. 52.04 1.20. SAND, grading to CALCAREOUS CLAY. Lower 40 cm very fine grained, loosely cemented by quartz overgrowths (original grains rounded) calcareous at base. Heavy minerals 1%. Dusky yellow (5Y4/1). Clay is olive grey (5Y4/1) and has white vertically oriented streaks and sheets of carbonate. Contact with overlying unit is sharp and wavy.

Unit 2. 56.60 1.94. No recovery.
0.22. SAND, very fine grained as for base unit. Contact with underlying clay irregular, with mixing.
1.10. CLAY, as for base unit 1, silty top, with moderate yellow green clay patches which become dull on exposure (7GY4/1, 5Y5/2, 5Y4/2). Obscure lamination.
1.00. No recovery.
0.20. SAND, very fine grained, scattered medium, polished grains. Opaques common. Some patches moderate yellow green clay (7GY4/1–5Y4/2).

Unit 1. 1.20. CLAY, waxy lustre on curved irregular fractures. Rare angular white carbonate lumps and streaks. Olive grey (5Y5/2).

NAMBA FORMATION

Supplementary Section Outcrop, West Side Lake Tarkarooloo, Section 13, Fig. 14

Section 13A, north of the northern track crossing Lake Tarkarooloo.

COONARBINE FORMATION

0.10. SAND. Very calcareous, with numerous 1–5 cm dolomite nodules and ferruginous sandstone lumps (reworked from Namba Formation), 5YR8/6.

— Disconformity —

EURINILLA FORMATION

2.30. CLAY-SILT-SAND. Silt (dominant) to fine grained sand, poorly sorted. Lower 10 cm moderately sorted medium grained sand. Up to 50% reworked dolomite nodules (pisolitic) of granule to pebble size in lower part, 7½ x 5 cm maximum size, and little evidence for abrasion. Upper 10–70 cm with gypsum nodules and carbonate patches. Green-black ferruginous and manganiferous stain, otherwise light red-brown 2.5YR5/6.

— Disconformity —

NAMBA FORMATION

3.85. CLAY, GYPSUM. Slightly silty clay, very hard, light weight, crumbly with greasy lustre. Colour

5Y5/2 to 5/1, mottled red-brown, yellow brown and black, specked with white gypsum flour. 80 cm horizon of cauliflowcroid gypsum nodules 1.10 m from top. Nodules 0.25–0.50 cm diam. with clay cores, not associated with any porosity change in host sediment.

1.25. DOLOMITE, CLAY. Lower dolomite 0.60 m clay 0.50 m upper dolomite 0.15 m. Lower dolomite nodular (intraformational conglomerate) at top, manganese dendrites throughout. White, very fine grained, with 5% angular silt. Upper dolomite contains ostracodes. Clay as above.

1.95. CLAY. 5% angular silt to very fine sand, grading to sand at base and dolomite at top. Very hard, light, dry and crumbly, with manganese stain.

1.45. SILT. Silt and very fine sand, becoming clayey at top. Bioturbated at top, 2–3 cm burrows, otherwise finely laminated. Minor bright green clay laminae. Top 40 cm impregnated with gypsum, mottled orange brown. Very light grey to white overall. Lower contact sharp, flat.

1.70. CLAY-SILT, DOLOMITE. Clay with 40% silt, 5–10% very fine sand. Arenaceous fraction of moderately sorted, angular grains. Colour 5Y6/1, orange to orange-brown mottling. Nodules and patches of greenish-white very fine grained sandy dolomite, weathering as 2 cm granules at top and bottom. Black stained.

0.78. Alternating SAND and CLAY. Sand beds range from silt to very fine sand, colour 5Y8/2. Clay is sandy. Individual beds 2–27 cm. Lower beds have sharper contacts and are laminated, very finely cross-bedded and lensing. Orange brown mottling and gypsum in upper part of section. Minor nodular dolomite.

0.80. SILTY CLAY. Silt to very fine sand 10–20% subangular frosted grains. Clay has greasy lustre and 5Y6/2 colour. Upper contact very sharp, flat.

1.00. SAND and DOLOMITE. Sandy clay and clayey sand with dolomite nodules 2–30 cm thick at top and bottom. Sand is subangular to subrounded, moderately well sorted, with frosted grains. Weathers to hard light brown sandstone, base cemented with gypsum. Sandy clay is 5Y5/2, clayey sand 5Y7/3, mottled with yellow green patches, and black patches at base (N1–N5). Very sandy parts are 10YR6/2–5YR5/2 at base.

Dolomite is very fine grained with botryoidal upper surface, in way, lensing beds. Greenish upper surfaces.

0.30. SAND. As above.

0.33. CLAY. Mottled clay and very fine sand, finely laminated beds which are irregular and lenticular, and have yellow green (10YR6/6) clay patches and, cross-cutting brown (10YR8/6) patches with black centres. Sand (5Y7/2). Basal 2 cm fine white sand. Gradational upper contact. Contains dark brown to yellow-orange irregular silcrete and ironstone nodules.

0.02-0.03. CLAY. As above. Sharp contacts.

0.23. SAND. Very fine, yellow green clay lamellae. Obscure medium cross bedding, straight foresets. Stained greenish black. Sharp upper contacts.

0.25. CLAY. As higher in the sequence. Upper 5-10 cm dolomitic, yellow-green and brown mottled.

0.10. SAND. As above. Obscurely cross-bedded, selenite cement at base.

1.30. CLAY. Silty. Very finely laminated, with very small scale cross-bed sets. Colour 5Y6/0.5, occasional black and brown patches. Upper contact sharp, flat.

0.70. CLAY. Slightly silty, hard, with sub-conchoidal fracture and greasy lustre. Selenite on contact with overlying unit. Slight greenish brown tint, otherwise N4.

Section 13B, south of the northern track, crossing Lake Tarkarooloo (200 m south of section 13A). Constructed from a series of breakaway slopes, and a scoured channel in the centre of the lake. Beginning from the top of the black clay, as at the base of the previous section, the sequence is as follows (from gully sequence):

3.5. CLAY. Dark grey clay with irregular shiny surfaced fractures, becoming lighter coloured towards base. Crops out poorly, forming low angle vegetated slopes. Upper contact sharp, flat. Lower contact moderately sharp to disturbed.

2.1. SAND. Very fine to fine grained, black stained. Thin 5 cm beds and fine laminate. Brown silcrete nodules throughout. Thin horizon of DOLOMITE nodules at top. About 20 cm above the base are 10 cm of laminated silty limestone with low amplitude symmetrical ripples, mud cracks, and 1–3 mm long tubules of organic origin. Sharp basal contact with . . .

0.25. CLAY. As at top of sequence (13B).

On a small noll isolated near the edge of the lake, the sequence continues as follows, with some overlap:

0.55. DOLOMITE. Sandy nodular white dolomite. Impregnated with gypsum and calcite, plus tabular black manganese concretions.

0.95. SAND. Fine grained, well sorted, laminated and silty at base. Cemented by gypsum and calcite in part. Numerous carbonate nodules exhibiting concentric structure. Some have vertical tubular disposition with an internal structure suggestive of shrinkage (c.f. silcrete nodules). Black and brown stain at base, with orange brown and yellow green patch stain. This, and the previous unit are equivalent to the 2.1 m of sand described above, with its bed of dolomite nodules.

2.5. CLAYEY SILT. Alternating hard clay and clayey silt in very fine lamellae (varve-like). Silty grey clay lenses. Yellow green patches with waxy lustre. Clay dominant at base. N5, 10Y5/4 to 6/6. Contact with underlying unit sharp, undulating: same contact as at base of 2.1 m sand described in gully section above.

0.5. CLAY. Hard, greasy lustre, irregular fracture. N3 at top grading down to 5Y4/1.

This clay crops out across the bed of the lake to its centre, where a scour next to a salt spring exhibits a further 2.5 m of massive hard grey clay.

NAMBA FORMATION *SUPPLEMENTARY SECTION*
SADM Wooltana 1 Stratigraphic Bore. Section 11, Fig. 3

?EURINILLA FORMATION
0.0 to 5.2 m No core
5.2 0.9 COBBLE CONGLOMERATE. Cemented with red-brown carbonate. Mica schist, gneiss, quartzite. Sandy (medium grained), with subrounded to well rounded, grains.

— ?Disconformity —

WILLAWORTINA FORMATION AND NAMBA FORMATION (intertonguing)
Unit 6
6.1 1.1 DOLOMITE. Sandy, clayey at base. 5YR6/4 to N6. Sharp upper contact, gradational lower contact.
7.2 3.8 CLAY. Slightly sandy, with dolomite nodules. Clay 7Y7/2 with red-brown vertical pipe structure. Sand subangular to subrounded. Some gypsum patches in lower part. Lower contact gradational. 50 cm core missing.
11.0 0.65 SAND. Fine sand, very poorly sorted, subangular to subrounded. Thin dolomite beds. Dolomite nodules. Clay at base.

11.65 to 12.50 No core

12.50 16.15 CLAY grading to SAND at base. Numerous dolomite nodules and some beds. Extremely poorly sorted medium sand to coarse silt. Some gypsum patches at top. Green and red-brown pipe structure. Sand subangular to well rounded. Sharp basal contact. 40 cm core missing in sand interval.
28.65 4.35 CLAY grading to SAND at base. As above. Mica in basal sand. 2.5YR/4–6, 5Y6/1 mottles. Sharp wavy basal contact.
33.00 5.6 CLAY, and DOLOMITE grading to SAND at base. As above, but dolomite beds in upper clayey part. Dolomite is 20% clay. Medium silt, extremely poorly-sorted. Sand subangular to rounded. Gradational wavy lower contact.
38.6 4.45 CLAY, grading to SAND at base. As above. Dolomite beds (brown) and nodules throughout. Sand patches at top. Lower contact gradational.
43.05 4.95 CLAY grading to DOLOMITE then SAND at base. As above. Mottled red-brown, green and yellow grey. Very poorly sorted. Minor core loss. Lower contact gradational.
48.00 5.15 SANDY CLAY grading to SAND at base. As above. Dolomite beds and nodules throughout. Sand laminated, micaceous. Intraformational clay and carbonate at base. Sand reaches medium grain size. Subangular to rounded. Disturbed irregular basal contact.
53.15 14.50 CLAY cf. NAMBA FORMATION. Patchy sand and carbonate near top. Reticulate network of carbonate "veins". Lower part with limonite nodules, irregular shiny black-stained fractured clay. Obscurely laminated in middle part. Sand very fine, angular to subrounded. 5Y6/1, 2.5YR6/2–8, 10YR8/2, 2.5YR5/6, 5Y7/1.5, 5Y6/1, 5Y5/5. 2–3 m core missing, mainly in upper part.
67.65 6.7 SANDY CLAY. Micaceous finely laminated silt becoming pebbly at 72 m, reverting to clay at base. Extremely poorly sorted. Granite, quartzite, shale, quartz and gneiss pebbles. Very angular to subrounded. Clay intraformationally brecciated and burrowed in lower part. Minor carbonate. c.f. WILLAWORTINA FORMATION. Gradational lower contact.

NAMBA FORMATION
Unit 5
74.35 4.9 Alternating DOLOMITE and CLAY. Dolomite (5–10 cm thick), oolitic white, aphanitic, with charophytes, ostracodes, molluscs and unidentified calcareous ?plant fossils. Numerous burrows in clay beds (all about 1 m thick). Micaceous silt in part. Bioturbated. Laminated at base. Sharp basal contact.
79.25 7.9 CLAY, minor DOLOMITE. Upper part similar to above, laminated and burrowed. Clay 6Y6/1+2.5YR4/6, becoming sandy at base, with rounded clay clasts. Basal contact gradational.
87.15 1.75 SANDY CLAY. Calcareous. 5Y5/1 to 5Y6/1. Sharp basal contact.
88.90 0.10 CLAY. Sharp contacts.
89.00 2.00 Interbedded DOLOMITE and CLAY. Dolomite as above. Very finely interlaminated with brittle, swelling clay. Shrinkage cracks common. Burrowed. Contacts on carbonate beds sharp and wavy to disturbed irregular. 7Y5/1, 5Y6/1, N3.5, 5Y4/2.
91.0 2.55 MARL and GYPSUM. Alternating thin selenite and calcareous clay. Sharp contacts on gypsum. Gradational lower contact. Black to dark olive.
93.55 4.60 CLAY grading to DOLOMITE and MARL at base. Numerous gypsum nodules, 4Y5/1, 5Y8/2. Mottled 5YR6/7. Minor gypsum laminae. Contacts wavy gradational to disturbed irregular. Intraformational brecciated.
98.15 3.55 CALCAREOUS CLAY. Irregular shiny fractures, oxidized red-brown patches. Swelling, very porous. Subaqueous shrinkage cracks.
101.7 9.15 CLAY. Sandy in centre, with selenite veins infilling slickensided joints. Sand laminated. Clay with irregular shiny surfaced fractures as above. 10–15% very fine sand to silt. Alternating colour pattern—oxidized red-brown clay passes down to 3Y4/2 to 6Y7/1 clay, has sharp upper surfaces. Basal contact irregular, disturbed.
110.85 7.1 CLAY. As above. Basal thin white dolomite. Churned structure suggests bioturbation.
118.00 7.45 CLAY grading to SILT in lower half. Silt well laminated, micaceous, very small scale

cross-laminated. Grains very angular to sub-rounded. Silt moderately sorted. Lower contact moderately sharp.

125.45 4.55 Alternating SAND, CLAY. Sand very fine, micaceous, small scale cross bedded, laminated. Lower contact moderately sharp.

129.00 1.80 As above. Lower contact irregular, wavy.

130.80 9.00 SAND, interbedded CLAY. Sand fine to medium, well sorted, small to medium scale cross-bedded. Micaceous and with clay balls. Grains very angular to subrounded. Sharp wavy contacts.

138.00 2.60 SAND. As above. Upward fining. Some clay at top, burrowed. Poorly sorted, average very fine grained. Wavy moderately sharp lower contact.

140.60 6.70 Alternating SAND, SILT, CLAY, CARBONATE. Sand as above. Carbonate nodular. Clay dark grey. Bioturbated and intraformationally brecciated. Mainly fining upward sequences. Sand dominant. Contacts irregular, disturbed.

Unit 3

147.30 26.10 CLAY grading to SAND in lower 1.5 m. Manganese nodules above sand. Minor sand bed at 157 m. Clay N5, numerous irregular shiny fractures. Sandy, averaging very fine silt, very poorly sorted. Sand and very fine silt, very poorly sorted. Sand very fine, burrowed and laminated. Very angular to angular grains. Irregularly disturbed lower contact.

163.40 1.80 SILT. 5Y6.5/0.25, orange brown mottles, obscure lamination, bioturbated. Sharp wavy lower contact. Grades to very fine sand at base.

165.20 3.4 SAND. Fining upwards from fine sand to clay. Thin clay bed with sharp contacts near top. Medium scale cross-bedded. 6Y6/1 to 5Y7/2. Sand poorly sorted. Moderately sharp wavy lower contact.

166.80 4.00 CLAY grading to SAND at base. Upper 1 m sandy, lower very fine obscurely laminated sand. Clay with irregular fractures, 5Y4/1. Sand beds have gradational contacts.

170.80 4.50 AS ABOVE. Minor sand at 172.2 m. Basal very fine sand, moderately sorted, obscurely small scale cross laminated, burrowed. Gypsum nodules. Clay as above with fractures and orange to red-brown mottles. Sand very angular to angular.

175.30 7.4 Silt. Laminated fine, very poorly sorted silt, gypsum nodules at top. very small scale cross-bedded, some burrows. 3 m missing in central part. Sharp wavy lower contact.

182.7 4.6 SANDY CLAY, grading to SAND at base. Cycle as above. Some calcareous zones, 5Y5/1, 5Y3/4. Sandy at 185 m. Basal sand fine grained, sub-rounded. Moderately sorted. Lower contact moderately sharp.

187.3 8.8 SANDY CLAY, SAND at base. Upper 3/4:N2 to 5GY7/0.5 clay as above with fractures and sandy patches. Dolomite nodules at contact with sand. Sand very fine to fine, very poorly sorted, 5Y6/1 to N8. Burrowed near top sand, rest bioturbated, obscurely cross-stratified.

196.10 0.9 SILT. Minor alternating clay and sand, sharp contacts. Silt laminated. Lower contact sharp and wavy.

Unit 2

197.0 14.0 Alternating DOLOMITE, CLAY, SILT and SAND. Complex inter-relationship between clay-dolomite cycles and sand and clay beds c.f. above. Contacts variable. Dolomite intraformationally brecciated. Silt laminated. Bioturbated and burrowed horizons. Clays with irregular fractures and orange mottles. Beds 40 cm–1.5 m thick.

211.0 16.3 Alternating LIMESTONE, DOLOMITE and CLAY. Consists of 1–2 m carbonate beds grading up to clay via disturbed zone. Clay beds burrowed or bioturbated, 10Y5/2 to 10YR7/2. Base of dolomite beds sharp and wavy. Dolomite aphanitic, white laminated, with oolitic zone. Ostracodes common, algal mats present. Zone 215–217 m of very narrow clay filled cracks. Irregular shiny fractures dominate in clay near base, otherwise absent. At top of this sequence is 5 cm goethite-limonite crust.

227.3 8.7 CLAY. Calcareous, intraformationally brecciated with numerous white carbonate specks. Irregular shiny surfaced fractures. N1 to olive green. Quartz rare, very fine to fine, angular. Lower contact gradational.

236.0 8.45 CLAY. Fissile pyritic carbonaceous very finely laminated clay with silt parting. Fine laminae of N1 to dark olive or 5Y2/1 colour. Numerous plant stem and leaf impressions or fruiting bodies, fish spines and scales, ostracodes (often in pure layers), gastropod protoconchs, spores and pollen. Burrows (pyrite filled) and bedding plane traces. Numerous pyrite-marcasite nodules. Some subaqueous shrinkage cracks.

WILLAWORTINA FORMATION *TYPE SECTION*

Western Nuclear WC2 Bore. Section 10, Fig. 3

?COONARBINE FORMATION and ?EURINILLA FORMATION

0.00 to 7.05 Cuttings only. SANDY PEBBLES, SAND. Micaceous, calcareous, impregnated with gypsum (except sand). Angular to very angular, 2.5YR4/8, 2.5YR3/6.

— Disconformity —

WILLAWORTINA FORMATION—MEMBER 3

7.45 0.44 No recovery.

7.89 1.65 SAND as below, 1–3% muscovite.

9.54 0.30 No recovery.

9.84 3.95 SAND grading to SILT. Sand very poorly sorted and very fine grained, silt coarse, pebbly and micaceous. Thin pebble bed grading up to sand at base. Porous zones impregnated with gypsum.

13.79 0.25 No recovery.
14.04 1.21 PEBBLY CLAY SILT, poorly sorted, with basal pebble bed, impregnated with gypsum.
15.25 1.50 No recovery.
16.75 0.24 PEBBLES, subrounded to rounded. Coarse feldspathic gneiss, fine biotite quartz feldspar gneiss, purple stained coarse feldspar.
16.99 0.68 No recovery.
17.67 0.13 SAND, pebbly, coarse grained. Feldspars, muscovite, biotite.
17.80 1.98 No recovery—a few abraded pebbles.
19.95 0.24 SAND, fine grained and micaceous.
20.19 0.22 No recovery.
20.41 0.38 GRANULES grading up to PEBBLES.
20.79 1.45 No recovery.
22.24 0.28 GRANULES to SAND, medium grained. Larger grains subrounded. Mica 5%, pink potash feldspar 15–20%.
22.52 0.64 No recovery.
23.16 0.33 CLAYEY SAND, very fine grained and micaceous, sharp wavy content with overlying 20 cm of COBBLES. 5–10% muscovite, pink potash feldspar. Yellowish grey (5Y7/2).
24.4 1.49 No recovery.
24.98 0.11 SAND, grading up to GRANULES. Sand medium grained with dull, pitted or shiny surfaced, angular to subangular grains. 15–20% feldspar (mostly pink potash variety). Muscovite and biotite flakes in the quartz.
25.09 0.80 No recovery.
25.89 0.20 SAND, pebbly, micaceous and overall fine grained.
26.09 0.72 No recovery.
26.81 0.14 COBBLES, sandy.
26.95 0.47 No recovery.
27.42 0.17 Pebbly micaceous coarse sand.
27.59 1.00 No recovery.
28.59 0.27 SAND, grading over short interval to COBBLES at top. Sand is poorly sorted and micaceous, medium grained.
28.86 1.61 No recovery.
30.47 0.27 COBBLES, passing over short interval to medium micaceous SAND.
30.74 0.72 No recovery.
31.46 0.53 SAND, grading to COBBLES in upper half. Sand micaceous and poorly sorted, medium grained. Clasts pink quartzite with micaceous hematite, purple fine quartzite, vein quartz, large potash feldspar pebbles.
31.99 1.00 No recovery.
32.99 0.26 SANDY PEBBLES, micaceous.
33.20 0.58 No recovery.
33.78 0.30 SAND, coarse and poorly sorted, micaceous.
34.08 0.30 No recovery.
34.40 0.39 PEBBLY SAND, very poorly sorted, micaceous, coarse grained. Dusky yellowish grey (5Y6/2).
34.79 0.57 No recovery.
35.36 0.24 CLAY, sandy, micaceous.
35.60 0.62 No recovery.
36.22 0.13 PEBBLY SAND, fine grained, moderate reddish brown (2.5YR5/6 to 4/6).
36.35 2.00 No recovery.
38.35 0.30 COBBLES and PEBBLES overlain by fine grained CLAYEY SAND.
38.65 0.20 No recovery.
38.85 0.56 GRANULE bed, thin, overlain by thick SANDY COBBLY PEBBLE bed (white vein quartz, pink potash feldspar, pink ferruginous quartzite, coarse siliceous gneiss or granite, dark grey shale, weathered fine gneiss).
39.41 0.77 No recovery.
40.18 0.20 SAND as before, with clayey sandy cobble bed at top.
40.38 0.71 No recovery.
41.09 2.46 SAND, coarse at base, grading up to extremely poorly sorted fine sand. Vertically oriented reddish brown pipes.
43.55 0.29 No recovery.
43.84 0.53 PEBBLY SAND, sand medium grained.
44.37 0.23 No recovery.
44.65 2.77 Fine SAND as before, grading up to pebbly medium grained sand in upper 1/3.
47.42 0.18 No recovery.
47.60 1.47 SAND, poorly sorted and very fine grained, micaceous, with scattered granules, two thin pebble beds at base.
49.07 0.63 No recovery.
49.70 0.35 PEBBLES, passing over short interval to SAND, clayey, micaceous and fine grained, poorly sorted.

50.05 1.64 No recovery.
51.69 0.34 CLAYEY SAND, coarse and very poorly sorted, grading to boulders. Metaquartzite clasts.
52.03 1.23 No recovery.
53.26 0.29 SAND, micaceous and very fine, light yellow-brown (7YR5/6). Very poorly sorted.
53.55 1.25 No recovery.
54.80 0.50 SAND, very micaceous, very fine grained. Pebble bed in centre (granite, banded pink and white quartzite).
55.30 0.58 No recovery.
55.80 0.63 SAND, fine, grading up to fine grained with scattered granules.
56.43 0.30 No recovery.
56.73 0.44 SAND, as above. Feldspathic quartzite pebbles.
57.17 0.48 No recovery.
57.65 0.40 SAND, as above, pebble cobble bed in centre.
58.05 0.49 No recovery.
58.54 0.84 CLAY, and pebbly SAND, coarse grained. Grades rapidly to micaceous CLAYEY SAND, fine grained, in upper 30 cm.
59.38 0.69 No recovery.
60.07 0.56 SAND, as below, fining to fine grain size at top.

MEMBER 2

60.63 0.66 No recovery.
61.29 0.54 SAND, as below, no granules.
61.83 1.43 No recovery.
63.26 0.99 SAND, slightly clayey, medium grained, with granules. Coarsening upwards.
64.25 1.50 No recovery.
65.75 0.23 COBBLES: massive pink granite, very fine dark quartzite, pink feldspar with ?hornblende.
65.98 1.30 No recovery.
67.28 0.10 SAND, medium micaceous and clayey.
67.38 0.19 No recovery.
67.57 0.34 GRANULES, grading to CLAY-SILT.
67.91 0.84 CLAYEY SAND, coarse, pebble interbeds.
68.75 0.05 No recovery.
68.80 0.47 SAND, coarse and poorly sorted, pebbly. Pebbles of quartz and gneiss.
69.27 0.14 No recovery.
69.41 0.41 SANDY CLAY, as before grading up to COBBLY SAND.
69.82 0.12 No recovery.
69.94 0.18 SANDY CLAY, as before. Micaceous.
70.12 0.25 No recovery.
70.95 0.85 Silty clay grading up to cobbles.
71.82 0.33 No recovery.
72.15 0.27 SAND, medium, grading up to CLAY.
72.42 0.13 No recovery.
72.55 4.07 SILT, extremely poorly sorted, medium size.
76.62 0.11 No recovery.
76.73 1.40 SAND, very fine, pebbly, grading to SANDY SILT CLAY.
78.13 0.95 No recovery.
79.08 0.85 GRANULES (lower 20 cm) grading up over short interval to SAND, clayey, medium grained, very poorly sorted.
79.93 0.17 No recovery.
80.10 1.68 SAND, very fine, grading to very coarse at top. 1% muscovite and biotite, 10–15% potash feldspar. Grains very angular to subangular and dull. Small grains shiny and faceted. Extremely poor sorting.
81.78 0.15 No recovery.
81.93 0.25 SAND, fine grained, very poorly sorted.
82.18 0.16 No recovery.
82.34 0.85 GRANULES, basal bed, grading over short interval to very poorly sorted CLAY, very sandy.

MEMBER 1

83.18 0.06 No recovery.
83.24 0.76 CLAY, lower 10 cm sharp contact with SAND, coarse grained to granule sized. CLAY thin bed at top. Extremely poorly sorted.
84.00 0.37 No recovery.
84.10 0.10 SAND, fine grained, clayey.
84.47 1.37 No recovery.
85.84 1.50 SILTY CLAY. Very poorly sorted, with thin coarse sand beds.
87.34 2.03 No recovery.
89.37 5.74 SILT, SILTY CLAY. Extremely poorly sorted coarse silt, silty clay micaceous. Thin coarse grained sand bed (91.2 m), above which the sediment coarsens from clay to very fine grained sand.

95.11 0.45 No recovery.
95.56 1.81 SAND, grading to CLAY at top. Sand very coarse, clay silty and micaceous with a thin granule bed near the top. Yellowish grey (5Y8/1).
97.37 0.26 No recovery.
97.63 3.79 SANDY CLAY, SAND. Sandy clay has medium grained sand fraction, very poorly sorted, grades to clayey coarse sand, with very angular to subangular pitted to shiny grains. Feldspar is common. The base of this interval is taken as the base of the WILLAWORTINA FORMATION.
101.42 1.08 No recovery.

—?Disconformity—

NAMBA FORMATION
102.50 2.30 CLAY. 15–20% subangular to subrounded sand, minor mica. Sand patchy near base, with irregular shiny-surfaced fractures (skew-planes). 5Y6.5/2 to 4Y5/1. Basal contact sharp. 30 cm core missing near base.
104.80 1.10 CLAY. As above. 10% sand, no mica, nodular and swelling with well developed fractures. Alunite mottles at base, 20 cm core missing in centre of interval. 1Y4/1, to 6YR6/1 at base. Sharp basal contact.
105.90 4.90 CLAY, grading to SILT in basal 60 cm. Intraformationally brecciated and burrowed (at 109 m) with some laminated intervals. Well developed alunite streaks, which decrease in abundance with depth, being absent at the base. 6YR6/1–6/2 grading to N8 at base. 70 cm core missing at various intervals, mainly near top. Basal contact irregular, disturbed.
110.80 10.50 CLAY grading to SILT at 144.4 m and SAND at 119.4 m. Clay intraformationally brecciated, 15–25% very angular to subrounded sand. Silt micaceous. Sand micaceous, cross bedded in 30 cm sets, and laminated, fine grained, well sorted. Grains angular to subrounded. Basal contact gradational. Weak alunite horizon 50 cm below top of unit, absent at 115 m. Colour 5YR5/1 above alunite, N8 below. 2.1 m core missing in silt and sand beds. Wavy indistinct lower contact.
121.20 0.70 SILT.
121.90 1.45 SAND. Micaceous, laminated, obscurely cross-bedded. Fine grained and moderately well sorted. Sharp lower contact. 70 cm core missing in centre of unit.
123.35 3.10 SAND. Minor clay at top, fine grained micaceous sand in centre, lower half grading to very coarse sand at base. Subangular to subrounded, large grains highly polished composites. Mostly no core, there being 50 cm recovered. Basal contact sharp.
126.45 9.45 SILT and CLAY (below 129 m). Clay, nodular, dark brown, silt greenish white. Sandy patches. Sand grains often show crystal faces—bipyramids. Indistinct contacts observed at 129.25, 129.4, 129.6 associated with weak alunite horizon. Colour 10YR6/2–5Y8/1 in this zone. Below 131.80 irregular shiny surfaced fractures and some alunite specks. Colour 5Y5/1–4, 5Y3/1. 17% silt. Grains very angular to angular. Much core missing throughout, recovery 40%.

WILLAWORTINA FORMATION *SUPPLEMENTARY OUTCROP SECTION*

"Wertaloona" Homestead Area. Section 1, Fig. 3

WILLAWORTINA FORMATION
Unit 9. 37.9 COBBLES. Brown quartzite cobbles in a matrix as for unit 6. Basal bed of almost 100% grey-blue limestone cobbles. Rare red sandstone, quartz and yellow-brown silicified carbonate cobbles in float. Exposure poor, top not exposed.
Unit 8. 37.9 49.2 SANDY CLAY, red brown.
Unit 7. 87.1 20.8 COBBLE to BOULDER beds. Matrix as for unit 6, cemented with secondary white carbonate which may be powdery and soft, or hard vughy and crystalline. Cobbles of brown quartzite with 20% blue-grey limestone (resembling Cambrian limestones). Rare very large boulders of grey massive microcrystalline quartzitic silcrete with large milky quartz pebbles.
Unit 6. 107.0 13.0 (approx.) CLAY SAND. Red brown very poorly sorted and calcareous.
Unit 5. 2.0 (approx.) COBBLES. Brown quartzite cobbles scattered through matrix as for unit 4. Lenses out along strike.
Unit 4. 7.0 (approx.) CLAYEY SILT SAND. As for unit 2.
Unit 3. 1.0 (approx.) PEBBLY COBBLES. As for unit 1, more matrix, thin and lensing along strike.
Unit 2. 5.5 (approx.) CLAYEY SILT SAND. Red brown, with a calcareous matrix, sometimes thinly laminated.
Unit 1. 140.1 4.0 (approx.) COBBLES. Brown quartzite pebbles and cobbles in calcareous red-brown silty sand, lenses of calcareous medium sand at base. The sandstone fills channels, which have groove casts on the base. Cementation is weak, and pebbles weather out readily with thin calcareous crusts. Proportion of matrix low. The unit cuts into deep red brown clayey silt, probably Namba Formation. Although the contact here is sharp, there may be an intertonguing relationship along strike. The unit grades laterally to the south into pebbly clayey sandstone.

The following part of the section is poorly exposed, and is yet to be fully described:

—Disconformity—

?NAMBA FORMATION
12.0 SAND. Very fine greenish sand grading up into silty grey-green clay with gypsum patches.

7.2 CALCAREOUS SANDSTONE. Very angular sand with soft crystalline carbonate cement. Contains pebbles of very angular sandstone, carbonate, rounded brown quartzite, polished milky quartz, chert granules.
51.2 CLAY. Dark green-grey clay with greenish-yellow-stained patches, slightly sandy. Thin white nodular dolomicrite is present near the base, and may be a facies variant of the previously described unit.
8.2 SAND. Reddish to greenish silty fine to medium sand.
8.2 CALCAREOUS SANDSTONE. Essentially a sandy limestone with about equal quantities of medium grained angular sand and lime. Weathers grey, with a sculptured rough surface.
144.7 CLAY. Grey green to olive, greasy irregular fracture, sandy and silty. Minor dark olive to grey clay. Mottled with red-brown iron oxides. The interval 430–350 m (measured from top of the unit 9 in the Willawortina Formation section) is very poorly exposed and deeply weathered.
Near the top of these beds in the northern part of the area, is a thin white dolomicrite bed.

— Disconformity —

?EYRE FORMATION
2.0 SANDSTONE. Massive calcareous medium grained sandstone, partly silicified, and capped by remnant silcrete, dipping with the section.
2.0 CONGLOMERATE. Granule to pebble-sized polished white quartz, grey chert, ironstone. Pebble to cobble-sized angular Middle Cambrian sandstone. All in medium well-rounded sand matrix, cemented by calcium carbonate. Pebbles are patchily distributed, and the whole crops out as a low ridge with cavernous weathering and of brownish grey colour. Medium scale cross-bedding is prominent. The unit has an angular unconformable relationship with the underlying Middle Cambrian red-beds, though dips are similar.

Appendix II

YOUNGER CAINOZOIC UNITS
FIG. 15 SECTIONS 2–9

(See Fig. 1 for locations, and main text for access and photo points)

SUPPLEMENTARY SECTION, COONARBINE FORMATION
SECTION 2

COONARBINE FORMATION
1.7 SANDY SILT, with basal pebble bed. Sand dark brown (5YR3/5). Size varies from silt to very fine sand, moderately poorly sorted. No bedding planes visible. Columnar structure well developed. Basal clasts may be small cobble size, and are of metamorphic rocks and quartz.

— Disconformity —

EURINILLA FORMATION
2.2–2.5 CLAYEY SILT-SAND. Very poorly sorted, with irregular-shaped frosted or pitted grains. Contains pebble lenses (though not in the figured section) and large irregular aphanitic greenish white sandy carbonate lumps. The latter are probably derived from the upper carbonate in Wooltana 1 bore (section 11, Fig. 3). At top of 0.5–1 cm diameter branching vertically oriented cylindroids of pinkish "chalky" textured carbonate, representing a fossil soil horizon.

— Disconformity —

0.2 CALCAREOUS SAND. Pebbly sand (coarse grained), solidly cemented by pinkish buff (5YR7/2) carbonate. Colour derived mainly from orange-stained quartz grains. Laminated and thin bedded. Beds dip, suggesting cross-bedding is present (outcrops seen in plan only, in creek bed).
Possibly represents Willawortina Formation, or unnamed conglomerate equivalents of Millyera Formation.

SUPPLEMENTARY SECTION, COONARBINE FORMATION, EURINILLA FORMATION
SECTION 3

Location, Curnamona *Siccus* map sheet. Air photo ref.: S. Aust. Dept. Lands Svy. 361, run 2, photo no. 4442. The section is situated on the northwestern bank of the Pasmore River, close to the point where it debouches in to Lake Frome.
RECENT
0.00–1.20 Mobile bright red-brown dune sand, sharp erosional contact with underlying units.

— Disconformity —

COONARBINE FORMATION
1.00–3.50 SAND. Yellow-brown, with large scale dune-type cross-bedding. Sharp erosional basal contact. A lag of pebbles (eroded from the Eurinilla Formation) is at the base.
Numerous broken mature snail shells are present in the upper part of the unit. Aboriginal artifacts, calcified tree roots, emu shell, and vertebrate bones occur in the uppermost level (or possibly on the upper surface in the case of the artifacts and emu shells).
Strongly developed columnar structure is present (resulting from soil processes).

— Disconformity —

EURINILLA FORMATION
1.80 PEBBLY CLAY-SILT and SAND. Sand at base, medium-grained, yellow brown, numerous pebbles and rare flat cobbles, cemented by gypsum. Pebbles are milky and clear quartz, and very angular fragments of calcite-cemented conglomerate, overlain by bright red-brown silty clay

Unnamed Conglomerate (?Millyera Formation equivalent)

0.15 CONGLOMERATE. Thin, calcite cemented. Pebbles weather out without adhering crust. Pebbles as for overlying unit plus ?Namba Formation dolomicrite, and brown carbonate nodules from Willawortina Formation. Carbonate penetrates into top of underlying bed.

— Disconformity —

WILLAWORTINA FORMATION

2.05 SILTY CLAY. Sandy, greenish-brown with red-brown mottles, hard. Patches of gypsum nodules. Partly calcified at top. Blocky columnar structure visible (resulting from soil processes). Upper contact sharp, undulating.

MILLYERA FORMATION TYPE SECTION
SECTION 4

0.30 SAND. Reworked from older unit into base of dunes.

0.70 SAND. Coarse grained, with many gypsum grains and anomalous pebble sized angular quartz (milky). Powdery hummocky gypsum often developed at top (soil profile).

— Disconformity —

EURINILLA FORMATION

1.10 CLAYEY SAND. Very fine-grained, sub-rounded to rounded, good sphericity, moderate sorting. Numerous charophyte oogonia. Many greenish, yellow and brown grains. Colour 5YR5/6. Capped by gypsum crust, of gypsum nodules in clayey sand (groundwater deposit).

— Disconformity —

MILLYERA FORMATION

Unit 7. 0.50 CLAY. Soft, conchoidal fracture. Contact with overlying Eurinilla Formation sharp and flat. Very dark yellowish brown. The oxidized crumbly appearance and shiny surfaces (cutans) on crumbs suggest soil processes have operated, and indicate a disconformity between Millyera and Eurinilla Formations.

Unit 6. 0.40 SAND. Very fine to medium grained. Grains subangular to rounded and frosted. Charophyte oogonia .5%. Grades by alternation, to . . .

Unit 5. 0.50 CLAYEY SAND. Sand fraction well-sorted, with subangular to angular rounded grains, sharp flat upper contact. Greenish yellow (10Y7/2).

Unit 4. 0.70 CLAYEY SAND. Interbedded thin clay and very fine to fine clayey sand 0.25–0.50 mm thick. The sand is very well sorted, with subrounded to rounded high sphericity frosted grains. Darker oxidized clay present. Yellowish grey (5Y7/2). Lower contact gradational.

Unit 3. 0.30 CLAY as for unit 1.

Unit 2. 0.40 LIMESTONE and CLAY. Near the top of the sequence each clay lamina grades up to charophyte stem-mould limestone (up to 1 cm thick). These limestone beds harden on weathering, producing sheets and slabs with a metallic ring when struck. Intervening lamellae are 0.5–2 cm thick. Some of the Charales tubules are oriented and small turreted gastropods aff. "*coxiella*" are present (henceforth referred to as "*Coxiella*"). An oxidized zone exists beneath the limestone. The limestones form a distinctive marker horizon 20–30 cm thick. Contact with unit 1 and unit 3 are gradational by alternation.

Unit 1. 0.10 CLAY, brittle, soft, waxy lustre. Distinctly laminated and thin bedded (1–5 cm), each lamina grades up to a thin fine silt layer with charophyte oogonia and Ostracoda. White carbonate granules occur near the base of the sequence. Scattered medium polished or frosted quartz grains, sometimes up to 40% of the rock, occasionally forming sand lenses. Yellowish grey (5Y6/2—clay, lighter for sand). Base not exposed.

SUPPLEMENTARY SECTION, COONARBINE FORMATION, EURINILLA FORMATION, MILLYERA FORMATION
SECTION 5

0.00–3.50 SAND. Red brown sand of modern dunes reworked from Coonarbine Formation.

COONARBINE FORMATION

1.00 SAND. Light brown. Numerous vertically oriented small cylindroids of soft white carbonate, of soil profile. Emu shell, aboriginal artifacts and rare mature snail shells occur in uppermost level. Forms longitudinal dunes.

— Disconformity —

EURINILLA FORMATION

Unit 2. 4.00 SAND, fine to medium grained, with subangular rough or pitted grains, poorly sorted. Stratification absent. Grades to unit 1 over short distance. Light brown (5YR4/7).

Unit 1. 4.00 SAND, medium grained, brown (5YR6/6), lighter coloured beds alternate near base. Cross-bedded, sets 40 cm, lensing, gently curved coarse and fine laminae, sharp eroded upper contacts, assymptotic bottomsets. Laminae 0.5–1 cm, by variation in clay content. Sets are gently inclined toward Lake Millyera. Numerous charophyte oogonia.
Lightly cemented with clear or white finely crystalline carbonate. Pinkish irregular nodules, weathering as brown lumps and slabs on surface. Carbonate gives white cast to this part of the section, and causes slight benching. Partly cemented with massive gypsum in the basal layers.

— Disconformity —

MILLYERA FORMATION

Unit 5. 1.60–2.50 CLAY. Very hard, shiny irregular fractures, coated with black iron oxide and white carbonate at top (soil horizon). Impregnated with vertically oriented gypsum masses, in 5–10 cm columns (fossil groundwater horizon) at top. No silt content. Colour 10Y6/2. Similar to Willawortina Formation. Upper contact sharp, flat. Grades down to light green soft clay interbedded with very fine grained white sand rich in charophyte oogonia. Intertongues with unit 4.

Unit 4. 4.00–5.00 SAND. Silt to very fine grained sand, with coarse lenses. Numerous thin 0.5–5 cm clay beds and lamellae near top, which are crowded with algal tubules (charophytes). Some rare massive charophyte crusts consisting entirely of strap-like algal forms with numerous large oogonia. Charophyte oogonia common in upper sands. Clay pellet layers common. Sand grains are subrounded to well-rounded smooth or frosted, with moderate sorting. Small scale cross-laminated sets, 10 cm thick, with curved laminae.

Upper surface may be cemented with gypsum of a fossil groundwater horizon.

Unit 3. 0.00–0.93 SAND. Very fine grained, well sorted. Colour 5YR6/8. Impregnated with massive gypsum and disc-shaped crystals of gypsum. Grades by alternation of 1–4 cm thick beds into overlying unit, in which it forms a lense. Contacts between lamellae are wavy, lenticular, and rippled in some cases. Resembles Tirari Formation. Basal angular quartz granule layer, often resting directly on underlying gypsum sediment.

Unit 2. 0.25 LIMESTONE-GYPSUM. Greenish slightly sandy clay with 20 cm of interbedded thin (0.5 cm) gypsum laminae at top, which grades laterally into laminated algal stem (tubules of charophytes) limestone. The limestone and gypsum contain charophyte oogonia. The gypsum contains scattered very coarse sand grains, and surfaces are assymetrically ripple-marked, or have botryoidal "puff" structure.

Unit 1. 0.70 SAND. As for unit 4. Orange and yellow stained, especially near base, greenish where unoxidized. Reworked distorted clay fragments from underlying units at base.

— Disconformity —

NAMBA FORMATION

3.28 SILTY CLAY, grey to black, tough. Grading down to grey, clayey, poorly sorted fine sand. Greasy lustre on iregular fracture surfaces. Gypsum patches and cracks at top infilled with overlying sand.

SUPPLEMENTARY SECTION, MILLYERA FORMATION
SECTION 6

EURINILLA FORMATION

At least 2.0 bright red brown SANDS.

— Disconformity —

MILLYERA FORMATION

Unit 7. 0.20 CALCAREOUS SANDSTONE. Very fine to medium grained moderately sorted sand, 30% carbonate. Grains pitted or frosted, subrounded to rounded, alternates with very fine sand. Coarser sand contains charophyte tubules and rare oogonia. Some pink and black sand grains, rare carbonate grains. Weathered colour white (N10), unweathered greyish yellow (5Y8/4).

Elsewhere passes to hard platy limestone identical with 2. Impregnated with numerous white gypsum cylindroids. Gradational contact with 6.

Unit 6. 0.62 SAND. As for sand in 3 but uncemented, distinct contact with 5. Colour moderate reddish yellow (2Y7/4).

Unit 5. 1.20 CLAYEY SAND. Moderately sorted, with black and orange grains scattered throughout. Irregularly cemented into very hard massive nodules and sheets by fine grained white to pink carbonate. Yellow and brown mottling common near base, white gypsum and carbonate spots throughout. Yellowish grey (5Y6/2).

Unit 4. 0.25 SAND, SILTY CLAY. Grades from clay to very fine sand, grains poorly rounded. Colour yellowish (5Y7/2) oxidized to moderate brown (5YR6/7) in patches.

Unit 3. 0.5 LIMESTONE, CALCAREOUS CLAY. Varies laterally from burrowed soft calcareous clay, with 30% silt to fine sand, to hard sandy white limestone. The former has 1–2 mm diameter vertical burrows (insects?) and the latter has scattered charophyte oogonia and shrinkage cracks. The base of the burrowed horizon is gradational, and lumps of the underlying unit are worked into it.

Unit 2. 0.10–0.20 LIMESTONE. Laminated, platy, hard, metallic ring when struck. Constitutes numerous tubules of charophytes, and patches of "Coxiella". Contact with 4 not observed, contact with 1 distinct, undulating.

Unit 1. 0.50. On east side of channel, SAND, very fine grained, nodular white carbonate at lower contact. Pale grey. Massive carbonate-cemented at top with shrinkage phenomena apparently related to drying of carbonate.

On west side of channel. CLAYEY SAND. Moderate to well sorted, angular grains. Yellowish grey (5Y6/1) but speckled yellowish green. Grades up into unit 3.

NAMBA FORMATION

0.10 Black tough clay. Sharp flat upper contact.

EURINILLA FORMATION AND COONARBINE FORMATION TYPE SECTIONS; MILLYERA FORMATION SUPPLEMENTARY SECTION
SECTION 7

Modern dune sands

— Disconformity —

COONARBINE FORMATION

Unit 4. 0.70 SAND, very fine to medium grained, silty. Fine size dominant, well sorted, well rounded, frosted. Light brown (5YR5/6). At top is 20 cm of soft white carbonate, consisting of 0.5 cm cylindroids and tubules (plant roots?) with 1–2 cm lumps at the top, grading to blotchy white carbonate as for unit 2.

Unit 3. 1.62 SAND, bimodal, medium-coarse and very fine to fine. Bimodality disappears downward, grain size becomes finer, and sorting poorer. Some patches of white sand are present in the essentially moderate yellowish orange (9YR5/6) coloured sequence. Top is moderate reddish brown (3YR5/6). Large scale cross-bedding is just visible. A well developed fossil carbonate-rich soil horizon marks the top. It is 50 cm thick and consists of moderately hard rather irregular nodules and cylindroids, and gypsum cylindroids.

Unit 2. 1.80 SAND, fine-grained ranging to coarse, grades down to CLAY-SILT. Moderately poor sorting. No signs of stratification. Colour light brown to reddish yellow (6YR5/6–3YR5/6). Weakly developed whitish carbonate patches at top (soil horizon).

Unit 1. 1.00 SAND. Bimodal: on medium-coarse grained and very-fine grained boundaries. Dark red brown (2YR4.5/6). Indistinctly horizontally laminated, upper contact sharp and flat, lower contact obscure, apparently gradational.

— Disconformity —

EURINILLA FORMATION

Unit 3. 3.50 SAND, as above. Solour light brown (7YR6/4). Constitutes a single cross-bed set. Contact with unit 1, sharp, inclined, flat. Irregular gypsum as for unit 1 at base. Upper 10–20 impregnated with carbonate (10YR7/3) of a fossil soil horizon.

Unit 2. 4.00 SAND, friable, fine to medium grained, bimodal. Coarse fraction well rounded, dominant, colour light brown (6YR5.5/6). Constitutes a single cross-bed set, with low angle cross-bedding. Contact with underlying unit sharp, undulating, cuts well down into unit 1. Patches of very irregular tubules, nodules and cylindroids of gypsum occur at the top.

Unit 1. 0.88 SAND. Medium grained, sub-rounded to well-rounded grains with very fine grained angular proportion (bimodal). Numerous coloured grains, opaques and biotite present. Silty brown clay with gypsum forms pebble sized clasts, and clasts of underlying limy sandstone are present. Cross bed sets planar, 8–10 cm. Charophyte oogonia very common, and fragmental vertebrate bones present. White colour. Lower contact erosional.

— Disconformity —

MILLYERA FORMATION

1.1 LIMY SANDSTONE. Very fine to medium grained moderately sorted clear-grained quartz sand with 30–40% finely crystalline soft carbonate cement. Sand grains pitted or shiny, angular to sub-rounded. Some grains of feldspar and ferruginous sandstone, flakes of hematite. Thin section shows carbonate has recrystallized into radiating spherules, resembling some groundwater carbonates.

2.8 SAND, SILT. Silt to fine sand, 1–5% clay-carbonate matrix, forms strong cement by reason of poor sorting of framework grains. Very poorly sorted with sub-rounded to very angular grains. Hard and red-white mottled.

SUPPLEMENTARY SECTION, EURINILLA FORMATION

SECTION 8

Locality: CURNAMONA, *Eurinilla* map sheets. Air photo ref.: S. Aust. Dept. Lands Svy. 361, run 3; photo no. 4396. The section is situated on the west side of Lake Pinpa, approximately 50 m north of the only track crossing the lake.

Modern sand dunes

0.0–4.0 SAND. Fine to medium grained, moderately sorted. 5YR5/8. Strongly erosional base.

— Disconformity —

?COONARBINE FORMATION

0.50 SAND. Very fine to medium (averaging fine grained), poorly sorted, with sub-angular to sub-rounded polished or frosted grains (4YR5/8). Erosional basal contact.

This unit may represent the Coonarbine Formation. It forms the basis of the longitudinal dunes.

— Disconformity —

0.25 SAND. Very fine to fine, rather poorly sorted, clayey. Grains irregular, subangular, rough. Colour 5YR5/7. Soft patchy carbonate well developed, with pipe like structure 5 cm diameter. This is a soil horizon, and has a similar development to those of the Eurinilla Formation. The lithology is also similar but there is a distinct contact at the base which appeared slightly erosional. The unit may be part of the EURINILLA FORMATION.

— Disconformity? —

EURINILLA FORMATION

Unit 3. 1.00 SAND. Clayey, very fine to fine, poorly sorted. Angular to sub-rounded frosted and coarsely pitted sand grains. Colour 3YR5/8. Well developed secondary carbonate profiles constituting soft sandy pinkish white lime in lumps and cylindroids 1–5 cm across which weather out. In lower part of sequence fractured lumps 10–20 cm are common. The carbonate profiles form numerous layers, concentrated toward the top of the unit, and represent soil development (hence intermittent deposition is indicated).

Unit 2. 5.33 SAND. Poorly sorted silty, slightly clayey fine grained, rounded (2.5YR4/8). Grades imperceptibly into overlying unit.

UNNAMED CONGLOMERATE (?MILLYERA FORMATION equivalent)

Unit 1. 0.8 Interbedded CONGLOMERATE, SAND and CLAY. Consists of basal sand loosely cemented with calcium carbonate, cross-bedded on medium scale. Micaceous. At the base of this sand bed are granule size quartz (grey, clear, dark grey, yellow), pebble size clasts of grey clay and subrounded calcareous orange-brown clay. Also large grains of brown perthite feldspar. Maximum grain size is 1.5 x 2 cm.